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The Unpredictability of Complex Systems

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ABSTRACT

One of the findings of modern chaos theory is that complex systems are predictable in the short term, but not in the long term. There is an element of uncertainty in all complex systems. Furthermore, this fact holds true across a very broad spectrum of scales and reference frames. Does this finding hold true for human beings? When the human body and mind are considered as complex systems we should expect to find that our futures are reasonably predictable only in the short term, which does seem to be the case. Many of the findings of chaos theory have been transposed to other disciplines, including biology. However, more work needs to be done to transpose these important findings to psychology.

Introduction

Complex systems all have feedback mechanisms. These mechanisms provide the means by which matter, energy, or information are fed back into the system. Because material objects are not perfect, tiny errors will creep into the feedback process. In the short term these errors can often be ignored. But in the long term they can accumulate, through the repetitive feedback process of *iteration,* until the error (noise) is as large as the system input or output itself, making any predictions for the system impossible. Haken (1988) points out that deterministic chaos theory has shown us that even in classical mechanics, predictability cannot be guaranteed with absolute precision. However, according to Gordon (1991), in certain circumstances it is possible to forecast values in a chaotic series over limited ranges. Perhaps Kellert (1994) says it best when he states that complex systems are associated with "predictive hopelessness" (p 33). He also points out that if the "time between noteworthy events" is short enough, a dynamic system can have a "predictively worthwhile time," which tells us the time required for the situation to reach predictive hopelessness (p 34). In other words, complex systems can be predicted in the short term, but not in the long term. The fact

that deterministic systems can be unpredictable has required physicists to review these two terms. Today, most physicists agree with chaos theory and eliminate the requirement for predictability in their definition of determinism (Kellert, 1993).

The Chaos Theory of Unpredictability

The chaos theory of unpredictability is an extension of the well-known *Hiesenburg uncertainty principle* which states that

$$\Delta M_x \Delta x \approx h$$

where h is Plank's constant. Essentially, this equation implies that either the momentum of a particle, M_x, can be known with certainty, or its position, x, can be known with certainty, but not both together. This uncertainty is inherent in how we measure things, and exists because every observer tends to influence, to some degree, what is being observed. This basic principle of uncertainty at the quantum level has been verified many times in the scientific community. Chaos theory extends this uncertainty principle to the macroscopic level when we consider complex systems which are sensitive to initial conditions. In chaos theory, this principle is called *Prigogine's uncertainty* after the 1977 Nobel Prize winner in chemistry, Ilya Prigogine. Prigogine's new uncertainty principle says that as systems become more complex, a threshold of complexity will be reached such that the system will begin functioning in unpredictable directions; such a system will lose its initial conditions and these can never be reversed or recovered (Briggs and Peat, 1989). Mathematically, this is

$$dS_T = dS_I + dS_E$$

where dS_T is the total or net entropy, dS_I is the internal entropy (this is the traditional entropy of Clausius that can increase but not decrease for a closed system), and dS_E is the external entropy, or that which is exchanged by the system with its environment. The last term, which can be positive or negative, extends the traditional entropy definition to open systems (Çambel, 1993).

The future of any complex system is unpredictable. All that we can ever know of the future is in terms of probabilities. The future of any complex system can only be known totally (i.e., with certainty) by its moment-to-moment expression in the present.

The chaos theory of unpredictability tells us that the future is a world of possibilities. Every future event is associated with a probability of occurrence. We cannot even say that the sun will rise tomorrow morning with 100% certainty. However, chaos theory does provide techniques that make order out of apparent chaos. Probably

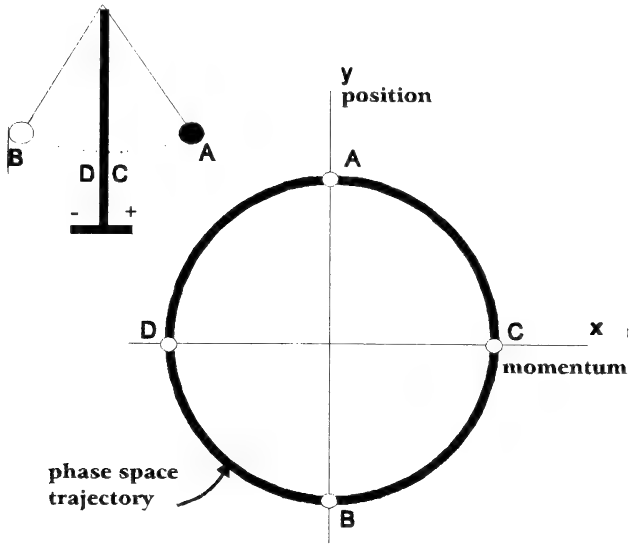

Fig. 1. A Simple Pendulum Showing a Plot of position vs. Momentum.

the biggest area of concern today is in the stock market (Weiss, 1992). Using chaos theory to predict the stock market has both adherents (Burke and Shirreff) and critics (Hulbert). According to Stambler (1991), chaos theory is currently being investigated for use in electric power research to predict energy usages.

Attractors in Phase Space

One dimension is a straight line. For example, if you are in one-dimensional space, you can only go forward or backward. Two dimensions is a plane. In two dimensions, you can go forward and backward as well left or right. In three dimensions, you can also go up or down. But fractional (or *fractal*) dimensions imply the ability to go between two and three dimensions.

Attractors are usually defined as a region in the state space of a system such that all trajectories nearby converge to it (Kellert, 1993). Attractors are said to reside in the state space of a system which is called *phase space*. Let's take a look at phase space and see if we can get a better grasp of just where it is located. We will use the classical case of a swinging pendulum as an example of a simple system (see Figure 1). Let's envision a bob swinging from a string. The pendulum has only two major characteristics, the position of the bob in time, and its corresponding momentum (mass times speed). We can let the lowest point of each swing, where the bob will eventually come to rest in time, be position zero. At the maximum height of each swing, just before the bob reverses its direction,

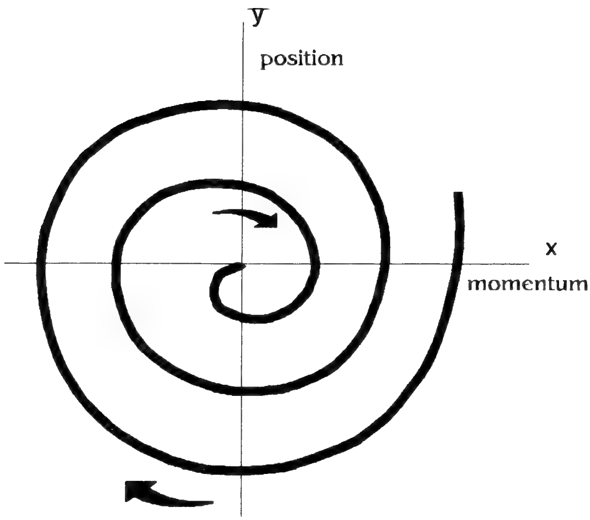

Fig. 2. Phase Space of a Simple Pendulum.

the position of the bob is the greatest, and its corresponding momentum is zero. We can make a simple plot of these two points on an xy-coordinate diagram such as that shown in Figure 1. The x-axis measures the momentum of the bob. The y-axis measures the corresponding position of the bob. We will mark these two points as A and B. Since momentum is zero, they are both plotted along the y-axis. For convenience, let's let a swing to the right be plus along the x-axis, and a left swing be negative. Point A is to the right of the swing and therefore is plotted as positive along the y-axis. When the bob is at the lowest point of a swing, midway between points A and B, its position is zero, and its momentum is a maximum. When the bob swings from point A to point B it crosses this lowest point, which is shown in Figure 1 as point C. When the bob swings back from point B to point A it again crosses the lowest point, but in the reverse direction (i.e., with a negative momentum). We call this point D on our plot. If we were to plot a lot of these corresponding points on our diagram, a circle would form around the center of the x and y axes as shown in Figure 1. A plot such as that given in Figure 1 is called a *phase space map.* The circle itself is called the *phase space trajectory* (because the trajectory here is a circle, it is usually called an *orbit*) and represents the entire motion of the pendulum for one cycle. Additional cycles of the pendulum will simply repeat the circle.

We all know that the pendulum, if left to itself, will not keep repeating this cycle. Experience tells us that in time, it will slow down and will eventually stop. This is shown in the phase space diagram in Figure 2. This attraction for the same fixed point is true with all pendulums, no matter their size. The magnetic

attraction of the orbit of the pendulum for a fixed point is caused by a special attractor known as the *fixed-point attractor.* These are stable equilibrium points where dynamic systems will tend to come to rest. According to Çambel (1993), "Dynamic systems are attracted to attractors the way fireflies are attracted to light" (p 59).

An easy way to think of the fixed-point attractor is to consider a ping-pong ball and the surface of the sea. We can drop the ball over the sea where it will fall until it contacts the surface. We can also hold the ball under the water and then let go, where the ball will float upward toward the surface. Either way, the surface of the sea acts as an attractor for the ball and no matter where the ball is released, it will always wind up on the surface. But once the ball reaches the surface, it will be buffeted by winds and currents in unpredictable ways because the dynamics of the surface of the sea are very complex (Cohen and Stewart, 1994).

The fixed-point attractor is one of four known types. Other types include the *limit cycle, tori,* and *strange attractors.* A fixed-point attractor draws a system to a single point in phase space. A limit-cycle attractor attracts systems to a cyclic path in phase space (a range of final resting points). The configuration of attractors in phase space can help determine if a system is conservative (maintains energy) or dissipative (energy must be supplied from outside the system) and can also help determine if a system is chaotic. They serve as the geometric counterpart to the thermodynamic entropy function (Çambel, 1993). Strange attractors are found in conditions of turbulence. They attract complex systems from order into disorder. Ruelle, who first called the attractor for turbulence "strange," found that this attractor pulled complex systems into a space of fractional dimension, where they became caught somewhere between a two-dimensional plane and a three-dimensional solid (Briggs and Peat, 1989, and Ruelle and Takens, 1971). To appreciate this situation, consider a piece of paper, which is essentially a two-dimensional object. Crumple the paper. As it is compressed, the two-dimensional sheet of paper will approach a three-dimensional object.

Reference Frames and Scales

A reference frame is an axis which we assume to be fixed, and by which we can make relative measurements. According to Einstein (1961), every measurement that we can make must be in relation to some fixed frame of reference. Our everyday world is such a reference frame. However, modern relativity has demonstrated that there is no such thing as a totally fixed reference frame. Everything is moving or rotating. Our world hurtles through space around the Sun, which itself is moving through space around the galaxy, and so on.

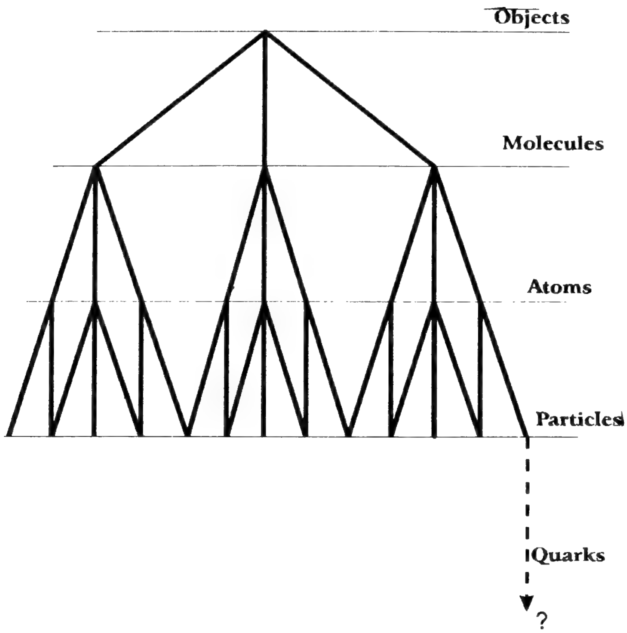

Fig. 3. The Reduction of matter.

There are two main kinds of reference frames: *inertial,* which is relatively fixed, and *noninertial* or accelerated, which is relatively in motion. Reference frames can be constructed at different scales.

This idea is graphically displayed in Figure 3 which depicts the current reduction of matter by modern physics. Take any physical object that you want. In our normal everyday reference frame, your object will appear to be solid and real. However, we now know that it is really made up of microscopic molecules. The rest is simply empty space (for purposes of this argument, we will ignore the theory of virtual particles which disprove the concept of empty space). When we change our scale to the molecular level, we can have another reference frame. If we look closer, we will see that each molecule is composed of atoms with everything else being empty space. We can change our scale to the atomic level and construct another reference frame. If we look deeply at each atom, we will see that they are composed of subatomic particles such as electrons, protons, and neutrons. The rest is empty space. We can change our scale to the subatomic level and construct another reference frame. If we look closely at subatomic particles called *hadrons,* we will find that they are composed of quarks (according to Murray Gell-Mann's quark theory). The rest is empty space. If we could change our scale to the quark level, we could construct another reference frame.

This idea has also been proposed by quantum physicists. As we saw earlier,

according to the *Heisenberg uncertainty principle,* we cannot measure both the position and momentum of a subatomic particle with accuracy. This is because when we measure the one, we simultaneously disturb the other thus making its value uncertain. For this reason, subatomic particles are said to have a probabilistic nature rather than determinant because we can only measure them in terms of probabilities (Herbert, 1985).

An example, currently used by scientists to demonstrate the idea of reference frames at various scales, is the question ''What is the dimension of a ball of yarn?'' From a large distance, we could say that it is a point, with no dimensions. As we get closer, we would see that it is a three-dimensional ball. When we get close enough to see that it is a single piece of yarn wrapped around itself, we would say that it is a one-dimensional object twisted into three dimensions. If we look at the yarn very closely, we would see that the strands appear as three-dimensional columns. From even closer, we would see individual one-dimensional fibers. This example clearly shows that the number of dimensions that we assign to an object depends on our relationship to that object, which in turn depends on the scale in which we are making our observations (Gleick, 1987).

Linear and Nonlinear

Most of us like to think that our world is linear. We like to think that our lives are continuous. In the world of mathematics, linear equations can be graphed as a straight line. They can be easily solved. They can be taken apart and put back together again.

On the other hand, nonlinear equations cannot be easily solved. They often cannot be added back together. Engineers must use *fudge factors* or *experiential constants* to arrive at meaningful solutions. We can say, then, that linear equations reflect order while nonlinear equations reflect chaos.

Differential equations describe the way systems change continuously over time. Differential equations also describe the way systems change erratically over time (Gleick, 1987). Linear and nonlinear changes over time are both found in complex systems. As much as we would all like to forget the nonlinearity of life, we must face it squarely, and come to terms with it.

Let's look at a simple pendulum, again. Aristotle taught that all things seek their natural state-the state that they would find if left to themselves. The swinging pendulum, according to Aristotle, was trying to get to the Earth, but was constrained by the string. Aristotle did not see forces, rather he saw changes, and things that desired to change (Gleick, 1987).

When Galileo looked at a swinging pendulum, he saw a form of regularity or

periodicity that could be measured. He believed that all things tended to keep moving as they were, unless acted on by an external force. The pendulum, he believed, would swing forever but for the forces of friction that slowly dampened its movements (Gleick, 1987).

Galileo also believed that a pendulum, of a certain length, would keep the same time, no matter how wide or how narrow its swing. A wide-swinging bob has farther to travel, but he believed that it would make up the difference by moving faster. In other words, he taught that its period is independent of its amplitude (Gleick, 1987).

Modern scientists have found that this is not true. It is only an approximation. As the pendulum's swing changes, a slight nonlinearity is induced. At small amplitudes, the nonlinearity is so small that it is negligible. However, it is there, and modern scientists have been able to measure it (Briggs and Peat, 1989).

The pendulum example shows us how easy it is to view the same thing in many different ways. Although we may be unaware of them, almost everything in our lives is associated with tiny nonlinearities. We usually dismiss these as unimportant. However, these things are sometimes amplified by feedback loops or *iterative processes* until they jump out at us when we least expect it, causing all sorts of problems.

Looking at a somewhat bigger picture, Einstein's general theory of relativity is expressed in mathematical equations. These equations are essentially nonlinear. In fact, the nonlinearity of his equations have led to the discovery of *black holes*—tears in the fabric of spacetime, where the orderly laws of physics break down and no longer apply (Briggs and Peat, 1989 and Hawking, 1988).

Weather Prediction

Our weather is an interrelated series of complex systems. In 1961, Edward Lorentz discovered the *butterfly effect.* He was trying to forecast the weather. He was running a long series of computations on a computer when he decided he needed another run. Rather than do the entire run again, he decided to save some time by typing in numbers from a previous run. Later, when he looked over the printout, he found an entirely new set of results. The results should have been the same as before. After thinking about this unexpected result, he discovered that the numbers he had typed in had been slightly rounded off. In principle, this tiny difference in initial conditions should not have made any difference in the result. But it did. From this, Lorentz determined that long-distant weather forecasts are impossible. Tiny differences in weather conditions, on any one day, will show dramatic difference after a few weeks, and these differences are entirely

unpredictable. This phenomenon is called the Butterfly Effect because if a butterfly flaps its wings in one country, it can effect the weather in another. Technically, it is called *sensitive dependence on initial conditions.* Although Lorentz's discovery was an accident, it planted the seed for what is now known as chaos theory (Gleick, 1987).

Discussion

Strange attractors, associated with complex systems tending toward chaotic conditions, are especially difficult to measure, although scientists have come a long way in only the last few years. Our body is a complex open system. As we go through life, we too experience the effects of attractors. We have single-point attractors like college or retirement, limit-cycle attractors, such as our tendencies toward habitual thinking, torus attractors such as our family and our attractions to other people, and strange attractors, such as sickness and disease. However, our ability to avoid many attractors in our daily lives constitutes the rationale for the probabalistic nature of our future. For example, we may or may not marry. We may or may not continue to think a certain way. In most cases, we may or may not avoid an attractor. When encountered, they often will cause us to change the direction of our life and thus send us on our way toward yet another attractor.

We can plan for tomorrow with a reasonable certainty. But our plans for ten years from today will be very uncertain. Heisenberg's uncertainty principle is known to be true on the subatomic level. Chaos theory suggests that an element of uncertainty is present in all scales and frames of reference, even in our everyday lives. Our lives are inherently unpredictable, at least in their details. For example, death itself is a certainty, a point of final rest and therefore a fixed-point attractor, but how and when we reach this attractor are generally unpredictable factors.

According to Çambel (1993), "the concept of free will is related to chaos" (p 193). Unpredictability ensures free will, and without it our futures would be forever fixed. The choices that we make today can cause very different effects in our future. Chaos theory suggests that our lives are not totally predetermined. Instead, because the world includes both order and chaos, our lives tend to oscillate between periods of free will and determinism, between sickness and health, and between planned events and accidents.

Many important findings of chaos theory have already spilled over into other disciplines. Hopefully, in the burgeoning spirit of interdisciplinary that we see in our universities today, some of these findings will be successfully transposed to psychology; a task made possible by considering the human mind as a complex system.

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Presenting Information for Fault Management

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ABSTRACT

While some issues of presentation of information are discussed here, the emphasis of this paper is on information content, that is, what information should be presented for management of aircraft systems faults, and additionally, when it should be presented. It is argued here that information requirements, as traditionally defined, fall short of describing the larger set of information that may be useful to the modern flight crew. We believe we can now recast information requirements in terms of human information processing tasks, rather than exclusively in terms of human actions and sensed data.

In the context of what information to present, this paper focuses on presenting information to support fault management performed by the flight crews of commercial aircraft flight decks. We discuss the characteristics of the application, and the similarities to and differences from fault management in other application areas. We discuss human management of faults using automation as an aid, and how this human-centered automation philosophy affects the design of the decision aid and determination of information requirements. The results of studies addressing the information needs and desires of flight crews are described, with a particular emphasis on the manner in which the pilots process the information to support fault management tasks. In addition to discussing presentation of information for managing failures, we also discuss the need to present information to manage the fault management aid. Lastly, we raise the issue of integrating the fault management aid with the remainder of the flight deck systems.

Presenting Information for Fault Management

For most human factors and human-computer interaction researchers and practitioners, discussion of presentation of information probably elicits concerns about issues such as format, color, symbology, and display media. While some of those issues are discussed here, the emphasis of this paper is on information content; in particular, what information should be presented to flight crews for manage-

ment of aircraft systems faults, and additionally, when it should be presented. "What" and "when" concerns are more typically described as information content or requirements issues, and are usually resolved prior to addressing information "form" issues.

It is argued here, however, that information requirements, as traditionally defined, fall short of describing the larger set of information that may be useful to crews of the modern flight deck. In the past, the pilot had a more physically-active role, and available technology limited the set of information that could be presented to a human operator to that which could be sensed, and a sensed value was usually displayed on a dedicated gage or dial. Correspondingly, traditional task analyses focused on observable tasks and information requirements were identified down to the level of detail where an information element was a sensed value. In these analyses, there was little application of research on human cognition by flight deck system designers. With the advent of digital computer and display technology, great strides have been made both in processing and presentation capability. Additionally, the role of the pilot in current generation flight decks accentuates cognitive abilities. Because of these developments, we now should, and can, present information that directly supports human information processing tasks, especially cognitive tasks, rather than just present sensed data that supports observable human actions. To do so, we must understand the human's cognitive activities, so that we can directly support those activities. For fault management, this means understanding the human information processing and decision-making processes involved.

It is also argued here, as elsewhere (e.g., see Malin, Schreckenghost, Woods, Potter, Johannesen, Holloway & Forbus, 1991), that information requirements should include information needed, as a consequence of pilots working with automated aids. These additional requirements include the need to monitor the aid, which we discuss below. The more cognitive nature of pilot activities, the new enabling processing and display technologies, and the new automation-induced information requirements, point to the importance of reassessing what information should be presented for fault management (with associated implications for when, how and where).

In this context, this paper focuses on presenting information to support fault management performed by the flight crews of commercial aircraft flight decks. We discuss the characteristics of the application, and the similarities to and differences from fault management in other application areas. We discuss human management of faults using automation as an aid, and how this human-centered automation philosophy affects the design of the aid and determination of information requirements. The results of studies addressing the fault management information needs and desires of flight crews are described, with a particular emphasis

on the manner in which pilots process information in performing fault management tasks. In addition to discussing presentation of information for managing failures, we also discuss the need to present information to help pilots manage the fault management aid. Lastly, we raise issues about integrating fault management aids with other flight deck systems.

Commercial Flight Deck Environment and Fault Management

The Domain

In modern commercial flight decks, two pilots work as a crew to manage the flight. Managing in-flight subsystem failures is a task they are only occasionally required to perform, because faults occur infrequently. As discussed below, even monitoring for system faults and failures is becoming obsolete because of the sophistication of automated alerting systems, the high reliability of systems, and the redundancy of system functioning. When failures do occur, the flight crew's primary goal is to continue safe operation of the flight. This contrasts with managing faults for the purpose of maintenance, for example. In maintenance, the operator's goal is to fix or replace the broken part of the equipment. Fixing or replacing the equipment is rarely an option in in-flight fault management. Because the tasks are different, the operator's information requirements are correspondingly different. Another complicating factor is that initial response to an in-flight failure is often time pressured, so the pilot does not have extra time to analyze the situation. This is why pilots are not trained to perform extensive diagnosis of a failure once it is detected, but rather to respond rapidly in some manner that hopefully will stabilize the situation.

In the commercial flight domain, since the flight crew is not performing fault management as its primary function, the goal of fault management is to control or compensate for the effects of the fault on the more important functions of flight control and navigation. This coupled with the aforementioned infrequency of failures means that pilots often do not have a great deal of practice managing failures, other than in their training programs. Moreover, current training programs do not require the pilots to have as much detailed systems knowledge as in the past. Systems management, including management of failures has become more automated (''Douglas new systems,'' 1990), with the consequence that pilots are not as involved with the systems as they once were.

Current Fault Management Philosophy

Up until the mid- to late-seventies, the number of unintegrated visual and aural fault alerts on commercial flight decks was proliferating at an alarming rate, and

there was no well-thought-out, standardized information presentation philosophy for fault management (Cooper, 1977). With the three-person flight crew, this was tolerable because the second officer could spend much of his or her attention and effort on systems management tasks, including fault monitoring and management. Still, it was obvious that improvements were in order. The trend toward two-person crews helped fuel the need for changes. In recognition of these issues, the Federal Aviation Administration, Douglas, Boeing and Lockheed (e.g., Boucek, Berson, & Summers, 1986) collaborated to begin development of guidelines for a standardized and integrated caution and warning system for commercial flight decks. The notion was to develop a standard set of visual and aural warnings and visual messages which would attract the crew's attention to the non-normal condition, indicate its level of urgency (caution, warning or advisory), identify the problem, and provide some feedback on the adequacy of the crew response (Boucek et al., 1986). The resulting caution and warning concepts formed the basis for all modern commercial aviation caution and warning systems.

The information presentation principles are elegantly simple: the urgency of any condition is conveyed by the same information that is used to alert (e.g., a master caution light and aural alert gets the crews' attention and indicates to them a "caution level" urgency requiring immediate crew awareness and future corrective or compensatory crew action). Level of urgency is redundantly conveyed by the color and position of messages identifying the fault. Pilots are trained to retrieve specific, prescribed procedures and checklists based on standard phrases used in the identification messages, thus standardizing responses and reducing the guesswork and the uncertainty (and the accompanying requirement for difficult diagnostic and other decision making processes) related to fault management. In summary, the current "information presentation" philosophy for commercial flight decks is to alert and convey the urgency of a fault condition quickly and precisely, and to identify the fault condition to a level of detail that allows differentiation of prescribed procedures.

Fault Management as Information Processing

From an information processing perspective, fault management can be described as a typical sequence of perceptual, cognitive, and response tasks, (e.g., see Wickens, 1984 for a standard information processing model). If the generic perceptual, cognitive and response processes were translated into specific fault management tasks, one might generate task labels such as fault monitoring, fault detection, fault identification, fault diagnosis, fault localization, assessing the effects of the fault, planning for operation with a faulted system, response planning and response execution to contain the fault, to correct the fault, to repair the fault, and to compensate for the fault and the effects of the fault. This involves

a considerable number of distinct types of information processing tasks. We will not elaborate on the subtleties of these distinctions, but the point here is that because of the nature of the commercial flight deck domain, fault management by the flight crews of commercial aircraft normally entails only a subset of these tasks: fault detection, identification and corrective and/or compensatory actions. Hence the current information presentation supports these tasks to the exclusion of others. As mentioned, much work has been done on consolidating and standardizing the presentation of information for these fault management tasks, particularly in the alerting area.

Presentation of information for other fault management information processing and response tasks such as fault monitoring and fault diagnosis, are de-emphasized in the commercial flight deck environment because, for the most part with modern technology, they are non-essential for responding adequately to the fault or failure condition. "For the most part" is not always, however. Further, "non-essential" does not mean "not useful." There are situations such as catastrophic faults, multiple faults, extremely rare faults, or routine faults with exacerbating circumstances, in which these other fault management tasks come critically into play. There are many documented cases where if the crew could have detected or diagnosed the fault more quickly or accurately, or planned for or compensated for the effects of the fault more effectively, lives would have been saved. Current aircraft fault management systems do not offer pilots much, if any, support in situations where these fault management tasks are essential. This is not a criticism of current systems; not only are these rare events, thus making expensive informational aids hard to justify, but more importantly, technology to provide more sophisticated information for tasks such as fault monitoring and fault diagnosis has not existed. Advances in information processing and display technology are beginning to change that.

As these technologies have progressed, more interest has been focused on intelligent fault management aids (Abbott, 1991; Schutte, 1989). Concepts such as Faultfinder (Schutte, Abbott, Palmer & Ricks, 1987) are intended to provide an array of informational assistance to fault managers. This includes more sophisticated information for tasks which are already supported, such as fault detection and identification, but more importantly, new information for tasks for which they have previously been left to their own devices. We are currently addressing the effects of these advanced information aiding capabilities and concepts, the accompanying human-automation integration issues, and the problems inherent in presenting informational support for situations containing uncertainty (the very reason they are traditionally human decision-making domains), on information requirements and information presentation issues.

Human-Centered Automation Philosophy and Fault Management Aids

There has been a great deal of interest recently in human-centered automation, or automation designed to support the human (Billings, 1991; Norman & Orlady, 1989). Billings (1991) defines human-centered automation as "automation designed to work cooperatively with human operators in the pursuit of stated objectives." This contrasts with technology-centered automation, where a function or task is allocated based on a comparison of human performance and machine performance for each function. Inevitably, as technology progresses, this approach results in more and more functions becoming automated. Unfortunately, this has undesired "side effects" (Wiener, 1985). These include:

- the pilot is more remote from the primary flight functions (i.e., "out of the loop," resulting in reduced situation awareness);
- pilots are forced into performing tasks for which they are not well suited, such as monitoring; and
- new human error types and decrements in overall human/system performance can occur that can nullify and even reverse the performance advantages of automating individual functions.

Additionally, when such automation performs reliably for some period of time, pilots may become complacent or overly reliant on the automation. All of these undesirable consequences have manifested themselves in incidents and accidents that have been attributed, at least in major part, to the interaction between the humans and the automated systems (e.g., NTSB, 1986).

Human-centered automation thus was born out of the need to keep pilots involved in critical flight functions (both to maintain situation awareness and because they occasionally need to perform as backups for automated functions) and the need to consider the overall performance of the human-automation system rather than system versus human performance on individual tasks and functions. Because of the recognition that cooperation and complementariness of the human and the automation are such important factors for the safe and efficient operation of the flight, human-centered or user-centered automation has become the goal of design of advanced systems or decision aids for any complex application where the human is involved (Billings, 1991; Rouse, 1991).

For a resulting system or aid to be designed to support the human, it is important to first identify the desired role of the human operator with respect to the automation. One way to view the different possible roles that the human can take on is shown in figure 1, which represents a continuum describing the allocation of processing and responsibility between the human and the system.

At one end of the continuum, the human receives only raw data and must do all processing of that data and perform appropriate actions. At the other end, the automation performs all processing and carries out the decision or answer to

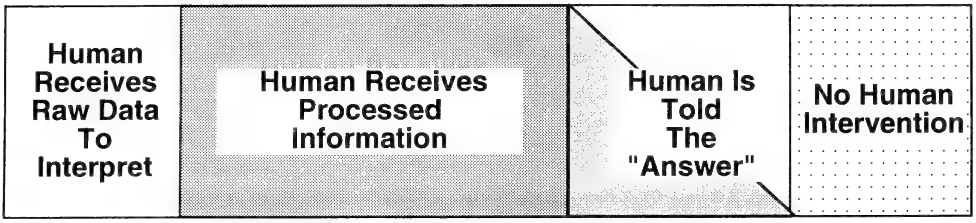

Fig. 1. Continuum describing possible human/automation roles.

whatever problem or task is being addressed. Between these two extremes, we have identified two categories that represent qualitatively different roles for the human/automation. In the leftmost of the two middle categories, the human receives processed information, but in the form of situation or status information. Much of the information provided by current caution and warning systems belongs to this category. The rightmost middle category is one where the automation does the processing, and provides a command or response recommendation about what to do, although the human actually carries out the action. An example of a system that falls into this category is TCAS, or Traffic Alert and Collision Avoidance System, a system which can give pilots a command, such as "climb right," to avoid other aircraft. The reason the two middle categories are separate is because in the category where the automation provides a command or response recommendation to the human, there is an opportunity for the human to follow the advice and do what the automation says without fully understanding the situation.

Clearly, this continuum represents only one of many dimensions along which human/automation role could be described. Others include approaches taken by Riley (1989) and Billings (1991). Nonetheless, it serves to support communication of two important points: first, the desired role of the human should be selected as part of an explicit design decision that is consistent with the automation philosophy chosen, rather than have the automation be designed and have the human's role be to monitor the automation and do whatever the automation does not do. Second, human-centered automation does not lie at a particular point along the continuum. Rather, the appropriate role of the human differs depending on the task. Many factors, such as time pressure, have a major effect on the choice of appropriate role of the human (and hence that of the automation). Thus, the pilot may have a different role for different tasks on the flight deck. We would argue, however, that human-centered automation means that when the total of all flight functions and tasks are considered, the human's role, in the aggregate, lies somewhere in the middle of the continuum.

Once the role of the human has been identified, the tasks to be performed

must be allocated to the human and the automation. As mentioned earlier, one commonly-used approach is to identify what humans are good at and what machines are good at, and allocate tasks accordingly (the "Fitts list" approach, e.g., see Fitts, 1951). As Woods (1989) points out, however, this human-automation comparability philosophy results in technology-centered automation with its associated drawbacks. Human-centered automation principles suggest that allocation of functions should be based on human-automation cooperation and evaluation of overall human/system performance. This idea is not new: Jordan (1963) wrote that "men and machines are complementary, rather than comparable." He went on to suggest that allocation of tasks to humans or machines is meaningless, and we should think about tasks as done by humans and machines.

Information presentation to the flight crew is complicated by human-centered automation, however. When a task or subtask is shared between the flight crew and the automation, the human operator must manage the automation. This may include monitoring the automation, understanding what it is doing, evaluating its output, and knowing how to interact with it. Because additional tasks are required of the human operator, there are corresponding additional information requirements.

We can see, then, that many factors affect the need for information: not only the fault management task, especially in terms of information processing tasks, but also design and automation philosophy, technology, and allocation of functions. Figure 2 shows a graphic depiction of some of the many factors that can affect information presentation to the flight crew and examples of affected content and form variables (Rogers, 1991). It behooves us to analyze the effects of all the factors on all the aspects of information presentation as directly as possible.

New principles defining the "what," "when," "how" and "where" (and "how much") of fault management information presentation are needed. These information presentation principles will emerge from an understanding of the underlying factors. Here, those factors have been divided into those dealing with an understanding of fault management and those dealing with an understanding of human-automation integration. Hence the subsequent division of the next two sections of this paper into sections titled "presenting information for managing the fault" and "presenting information for managing the fault management aid." It should be pointed out that as the technological ability to provide information becomes less and less constrained, pilots (and other operators too) become information managers as well as fault managers and automation managers. Although we do not address information management requirements here, others (Malin et al., 1991; Rogers, 1991) discuss the issue of information management as another set of factors that must be considered in defining information presentation principles.

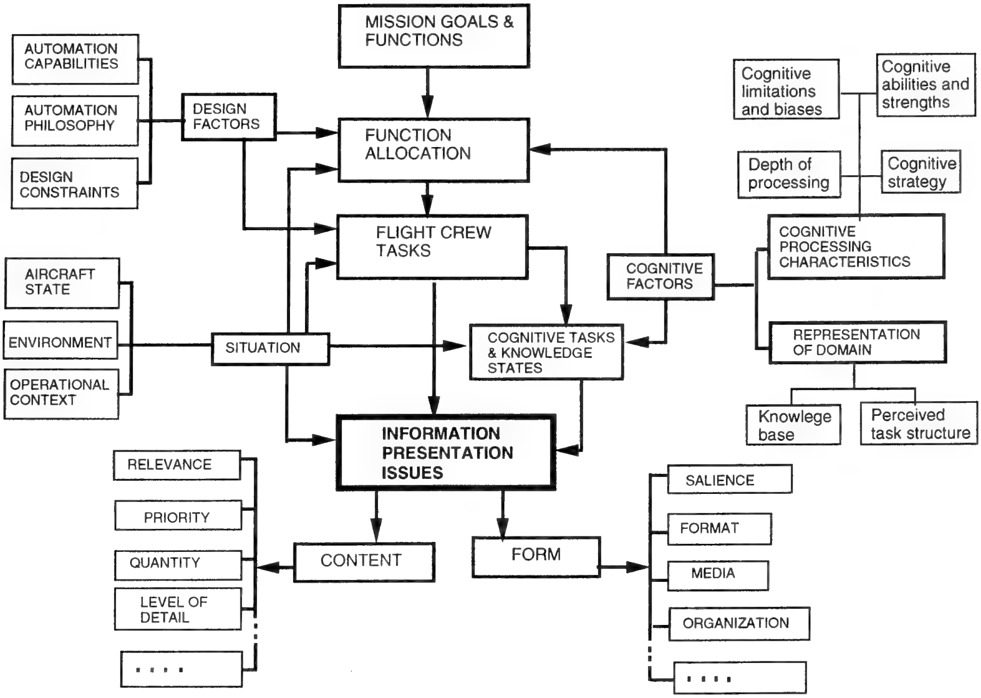

Fig. 2. Factors influencing the content and form of information presentation.

The following sections will raise some of the questions and provide some recommendations associated with this expanded perspective of information presentation for fault management.

Presenting Information for Managing the Fault

As mentioned, there are many information processing tasks involved in fault management. This section discusses cognitive task analysis as a way to gain insight into some of these tasks and as a way of identifying information requirements for fault management in general. Then, the Faultfinder concept will be discussed as an example of an aid for fault management, and information requirements for the specific tasks of fault monitoring, fault diagnosis, and determining appropriate responses will be addressed.

Cognitive Task Analysis of Fault Management

Cognitive task analysis provides a means of capturing cognitive activities associated with various operational tasks. As Roth and Woods (1990) point out, "there has been increasing recognition of the importance of performing a cogni-

tive task analysis as a basis for defining requirements . . . for decision aiding.'' We have used cognitive task analysis as a way to try to understand fault management tasks, and in particular, what information is needed to support them.

Cognitive task analysis can be thought of as a set of analyses aimed at understanding the cognitive processes involved in the conduct of a particular task or function. It is not a single analysis technique. In fact, loosely speaking, it is probably fair to say that the aggregate of experimental tools and techniques aimed at understanding human cognition comprise cognitive task analysis. Many studies have addressed human cognitive and information processes related to fault management. In several operational domains, Woods and his colleagues (e.g., see Woods, Roth & Pople, 1990), have investigated cognitive activities in regard to problem solving and emergency situations. Others (e.g., Rasmussen, 1982; Johanssen, 1983) have analyzed human fault management in nuclear power plants in terms of an information processing model, and described how individuals differ in the specific processing stages they use, depending on whether they adopt a knowledge-based, rule-based, or skill-based mode of behavior.

One way to get at the information requirements for fault management on commercial flight decks, especially in regard to information processing tasks, is to try to capture how pilots organize and prioritize various types of fault management information. If pilots organize information around different information processing tasks, as we hypothesize, then we can gain insight not only into information organization and prioritization, but also into the pilots' ''mental model'' of fault management; that is, in a generic sense, how they organize and prioritize fault management functions and tasks.

Such a study was conducted by the first author (Rogers, 1993). The objective of this study was to provide recommendations for presentation of fault management information based on how pilots mentally represent the fault management domain. This study was conducted in three steps: (1) fault management information types were identified, (2) pilots were asked to categorize and prioritize the information types in terms of a ''generic'' fault management situation, and (3) results were analyzed using scaling and clustering analyses to extract organizational schemes pilots use to group and rank information.

The information types were determined by conducting a series of structured pilot interviews, and by reviewing manuals and documentation of current and planned commercial aircraft as well as advanced fault management concepts such as Faultfinder (Schutte et al., 1987). These data were used to generate 26 generic types of fault management information. Examples of information types are:

- an alert that there is a fault
- a deviation of an actual parameter value from the expected value; and
- the cause or location of a fault or condition.

A description and example of each type of information was typed on an index card. A group of 26 pilots were asked to sort the cards into piles based on the similarity of the information and to rank order the cards based on general importance. The data were submitted to multidimensional scaling analyses and clustering analyses to determine how the pilots organized the information.

The results of the scaling analysis of the sorting data indicated that pilots generally think about fault management information along two dimensions, interpreted by the author as priority (or sequence of use) and stimulus-response. The priority dimension indicated that pilots think about information in terms of its priority or urgency. The scaling analysis of the ranking data did not reveal multiple dimensions underlying prioritization of information. The stimulus-response dimension suggested that pilots think about information in terms of whether it supports assessing the problem and situation, or determining consequences and actions. In fact, cluster analysis revealed that the stimulus-response dimension likely represents the natural sequence of information processing tasks: six primary clusters were found, and they were interpreted as information supporting the tasks of monitoring, detection and identification, diagnosis, detailed system status assessment, effects and consequences determination, and response.

The priority dimension of the scaling solution and the rank-ordering data both suggested that pilots want monitoring, detection and identification, and response information first. This corroborates the rationale of the current flight deck fault management information presentation philosophy. In terms of information processing, pilots are probably operating in a skill-based mode, and short-cutting deeper processing by associating shallow situation descriptions with pre-defined response requirements (e.g., see Pew, Miller & Feehrer, 1981). Interestingly, pilots indicated they would like the lower priority, "deeper" information such as detailed status, diagnosis and consequences later, primarily to confirm their understanding of the situation and the appropriateness of their responses. However, they want this information after they have stabilized the aircraft, compensated for the fault, and when there is less time pressure.

This suggests that pilots want information (and probably perform information processing tasks) consistent with the stages proposed by information processing models, but not in the typical order: the order of processing of information and the order of use appears to be different for fault management on commercial flight decks (Figure 3). It's not simply a matter of eliminating some stages by 'short-cutting'; rather, after an information processing short-cut to response information, 'backtracking' occurs in which the skipped stages of processing are performed after stabilizing responses are executed. These results have implications for what and when information needs to be presented, and which may best

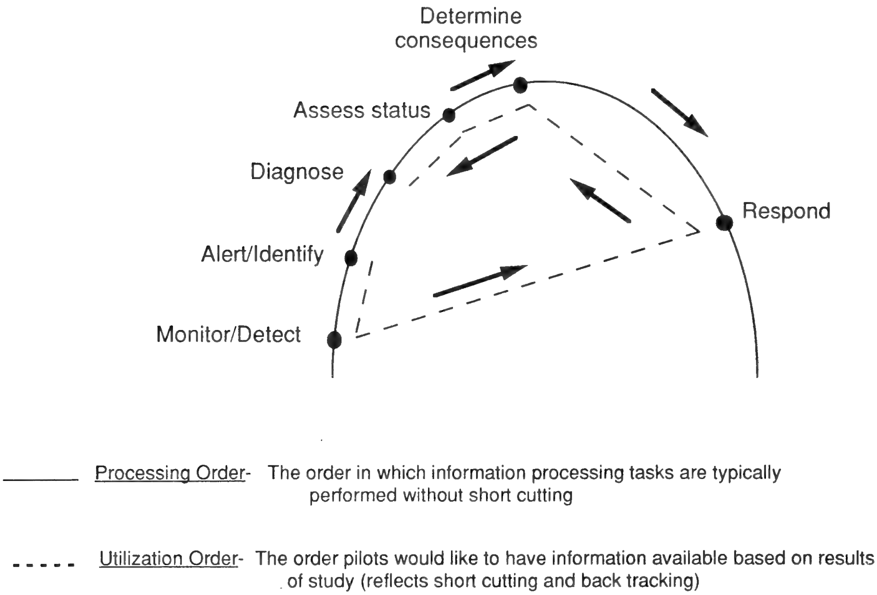

Fig. 3. The order in which information is typically processed versus the order in which it is typically used by pilots.

be presented automatically, which can be accessed at the pilot's discretion, and which may not be useful at all.

One caveat in interpreting the results of this study is important to note: since the "stimuli" grouped and prioritized by the subjects were themselves already categories (i.e., they were 'types' of information rather than individual instances or tokens of information), the possible ways that they could be further grouped by the subjects were necessarily dependent on the pre-groupings. Another pre-grouping strategy may have led to different results.

Studies using measures such as those just described, as well as verbal protocols, eye-tracking data, etc., help identify the information requirements associated with cognitive task performance, and hence are important elements of cognitive task analyses. These analyses help identify aspects of information presentation not addressed by traditional information requirements analyses.

Faultfinder

Faultfinder is an advanced concept for aiding flight crews in management of systems faults and failures. While it should provide improvements in the kinds of information that are presented by caution and warning systems on today's aircraft, it is aimed primarily at presenting new kinds of information to aid in fault management tasks that are de-emphasized in modern aircraft (at least from

the informational aid standpoint), such as fault monitoring, fault diagnosis, and response generation. Faultfinder was designed to generate information to support management of all faults, but particularly those which are difficult for pilots to manage, such as novel, complex, or multiple faults (Schutte et al., 1987; Schutte, 1989). It represents a substantial advance over current caution and warning systems with respect to the computational capability to generate types of information about fault situations, but comes with a corresponding increase in concerns about information presentation.

The information presentation philosophy of the Faultfinder concept is currently being developed, but simply, it is to present information to the flight crew that is consistent with their informational needs as they "walk" through the information processing stages associated with fault management, within the constraints of their environment. Additionally, since it is conceived as a human-centered automation concept, it brings with it requirements for additional information presentation associated with managing automation. And, although not covered here, because aiding concepts like Faultfinder have the potential for greatly increasing the overall information load on the pilot, information management issues need to be part of the information presentation philosophy as well.

Monitoring. "Information processing in most systems begins with the detection of some environmental event." (Wickens, 1984). However, flight crew monitoring for systems faults on commercial flight decks has not been a major concern in recent years due to the effectiveness of automated alerting systems in detecting faults and alerting the flight crew. Engine faults and failures have been an exception because it has proved difficult to develop engine sensors that could reliably distinguish faults from non-faults. However, for most systems, continuous parameter values are monitored by the automation and a discrete alert is activated based on a pre-determined threshold value. A system that just provides an alert to the flight crew may withhold accumulating evidence (e.g., actual parameter values or rates of change) that might be useful to the crew before the alert threshold is reached. After an alert has been activated, good parameter information can provide a needed source of confirming or refuting evidence of the problem. A premise of the Faultfinder concept is that better fault monitoring information may allow pilots to respond better, or better anticipate responses, relative to presentation of alerting information only.

Secondly, thresholds for alerts are currently set as hard limits; when a particular absolute value is exceeded, an alert occurs. In the case of engine instruments, this may simply be a color change on the parameter display. For many parameters whose normal values vary with the situation, absolute numbers may not be as important for monitoring the health or status of the system as the actual parameter value's relation to what is normal for that set of conditions. For many cases,

then, it is hypothesized that displays that depict actual parameter values relative to expected values should be more useful for fault monitoring than ones which depict only absolute values.

This is the basis for monitoring concepts such as E-MACS (Abbott, 1989) and the Monitaur module of Faultfinder (Schutte, 1989). Presentation of information for these concepts was based on analysis of the information processing required to perform the task, and in this case, monitoring of relative values rather than absolute values is a key aspect of the information processing associated with the fault detection task. Pilot performance of a monitoring task using the E-MACS display presenting relative parameter information was shown to be much improved over the traditional round-dial presentation of absolute parameter information (Abbott, 1990).

If the system can provide the expected "normal" value as well as the actual value, then the cognitive processing can be reduced and the task becomes essentially a perceptual matching one, which humans generally perform quickly and accurately. Of course, this depends on the relative values being displayed in a manner that is perceptually "salient," that is, that can be quickly and reliably noticed and decoded by the human monitor. A recent NASA study (Palmer & Abbott, 1994) showed that when a number of relative parameter values are to be monitored at once, a column deviation display (which shows the amount each parameter deviates from the expected value as an upward or downward bar extending from a centerline which represents no deviation), was more effective than a round dial that contained both actual and expected values. In a similar vein, object displays and other types of integrated displays use deviations from default object shapes to depict deviations in one or more parameters (e.g., see Carsell & Wickens, 1987; Buttigieg & Sanderson, 1991). These types of displays can exploit both the task-oriented notion of supporting monitoring tasks with relative values, and the human perceptual strength of being sensitive to salient, global changes in visual stimuli.

A key to all these relative value display concepts is the capability of the automation to compute nominally "normal" values. An obvious question that arises with this capability is, why not have the automation alert the pilot based on relative values. In other words, why not alert the pilot when a parameter value deviates from the expected value by some pre-set amount? While providing data and formats that enhance human detection of problems is desirable, certainly there is no question automation excels at monitoring and alerting functions. We are currently including the combination of better monitoring information and additional alerting information in up-coming simulation tests of Faultfinder.

Figure 4 shows an example of an engine parameter display we are experimenting with for one of these upcoming studies, in which both actual and expected

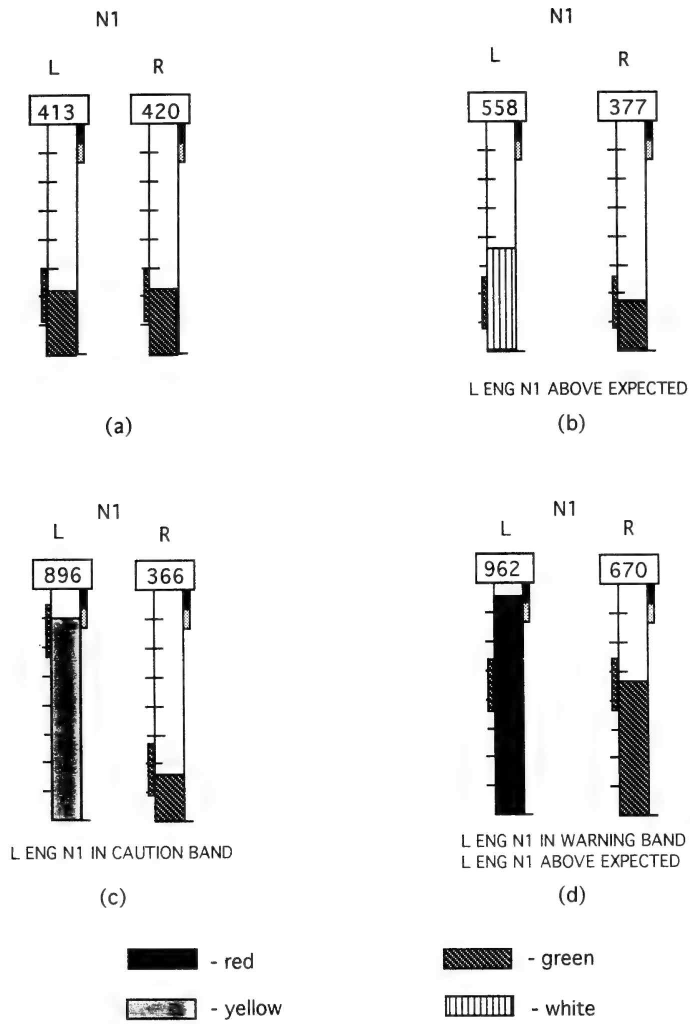

Fig. 4. Examples of engine N1 displays which depict actual values, expected values, exceedence bands, and appropriate alerting information for conditions in which parameter values are normal (a), deviate from expected (b), exceed the caution threshold (c), and exceed the warning threshold and deviate from expected (d).

values are shown, and alerts occur both for a deviation from expected value, and for exceeding absolute thresholds. The actual value is depicted by the digital readout and the fill of the thermometer. The expected value is depicted by the green band on the left side of the thermometer. Four different conditions are shown. When the actual value is within the expected range, and not exceeding the hard limits (condition a), the fill remains green. When the actual value goes out of the expected range (but does not exceed a hard limit), the fill changes to white and a white ''deviation'' message occurs (condition b). The notion is that a deviation from expected would be advisory level or informational, simply

informing the pilot to be more aware of that parameter or component because there may be a problem developing.

The hard limits are depicted by the yellow and red bands on the right side of the thermometer, and when the actual value reaches these values, the fill and digital readout change to yellow (condition c) or red (condition d). Values that exceed hard limits are accompanied by a corresponding yellow or red message. This would indicate a caution or warning condition which requires immediate crew awareness and immediate or imminent crew response (this is experimental; as mentioned earlier, the engine parameters on today's aircraft are not currently tied into the caution and warning system because of the difficulty in reliably predicting engine health from parameter values). If a hard limit is exceeded and a deviation exists, as in condition d, the color coding of the fill and digital readout would be driven by the value exceeding the hard limit, and the deviation would be apparent from comparing the expected value band with the actual value, and a "deviation" message would be presented just as it would if there was only a deviation condition. It is hoped that a concept such as this will offer the advantages of both automatic alerting for detection, and display of parameter data in reasonable formats to support the pilot's ability to use features of "raw" data, such as rates of change and relative values, particularly in relation to their superior knowledge of variables which may influence these.

As mentioned earlier, another possible advantage of presenting parameter data to pilots in addition to automated alerts, is that they can detect trends in parameter values and may be able to anticipate faults and failures before they occur, thus allowing them to get a "headstart" in managing the faults. A NASA study (Trujillo, 1994) evaluated different formats for depicting trend information. It assessed symbology that was hypothesized to enhance the ability to predict when an alert threshold would be exceeded or when a fault would occur from observing the rate of change of a parameter value for five or ten seconds. Although the experimental symbology did not appear to offer any advantage over standard symbology, it was noteworthy that for both an easy (constant rate of change) and moderate (decreasing deceleration) trend condition, pilots could fairly accurately (less than 20% error) predict the onset of an alert that occurred 20 to 80 seconds later.

Diagnosis. Once the existence of an abnormality is detected, another cognitive task is to diagnose the cause and the effects of the fault. In many applications, it is sufficient to identify the cause or source of the fault, so that the part to fix or replace can be identified. For in-flight diagnosis, however, it is also important to identify aircraft subsystems that are affected by the fault, but not necessarily broken. For example, an engine failure may cause an electrical generator to drop off line. The generator itself may be working properly, but because of the effect of the failure, the flight crew must take a corrective action. First, however, the

pilots must know that there is an action required. Additionally, since the aircraft systems are continuing to operate, the propagation of the fault over time must be understood to identify the changing system status.

For generating these types of diagnostic information, the diagnostic module of the Faultfinder concept, called DRAPhys (Abbott, 1991), was designed to diagnose these subsystem failures, especially faults that pilots have difficulty understanding or responding to, such as multiple or novel faults. To generate the diagnostic information about such faults, it uses qualitative models of the aircraft subsystems to identify the cause of the fault, its propagation behavior, and the resulting system status.

Deciding how to present this information to pilots needs to account for the fact that they are only trained to perform rudimentary diagnosis, and evidence indicates that they do not perform particularly well at this task. An aid might provide information to help pilots in areas where they have particular difficulty in performing diagnosis. In fact, the example of the engine failure is one in which pilots on current flight decks may receive an alert related to the electrical system, but may not get any alert on an engine failure, even though the engine was the cause of the electrical system problem. Under some circumstances, such as idle descent, once the pilots' attention is directed to the electrical system, they may fixate on it as the source of the problem, and only discover the engine failure when obvious cues (such as lack of thrust when the throttles are moved forward) become available.

Accurate diagnosis of system faults may be most important in unusual or complex failure situations. These types of situations may 'trap' pilots into inappropriately taking information processing short-cuts to quickly get to required responses. Not fully understanding the problem may lead them to err in deciding what to do. Yoon and Hammer (1988) addressed human performance in diagnosing novel faults, or faults the human had not seen or been trained to manage. In this study, they found that subjects provided with information about the discrepancies between observed and normal system behavior performed better in the diagnostic task. Note that this assumes a particular role for the human, with the aid supporting the human information processing tasks without actually solving the problem for him or her.

Given that diagnosis is not done very often and that they are not extensively trained for it, how do we support pilots performing diagnosis? It is generally agreed that they need to know the status of the system with which they are concerned, whether it is calculated for them or they figure it out themselves. If we show them status information, there is a wealth of literature on pictorial and graphical formats in which to show this (e.g., Summers & Erickson, 1984). Graphical or schematic presentations seem to be consistent with the way humans mentally model physical systems, although research by Kieras (1992) revealed

that it is useful to integrate the status of parameter information into the system status display, so that related parameters and system components were close to each other on the displays.

It is not so clear how to present other diagnostic information that we can now generate, such as fault propagation, nor is there a hard and fast guideline on when to present it. A recent study (Rogers, 1993) suggests diagnostic information should usually be presented after the situation has been stabilized and the flight crew has time to confirm its actions. Yet if the diagnosis is critical to choice of the correct response, which is exactly the case in which pilot errors might occur, diagnostic information should be presented immediately, as part of the 'identification' information which helps the pilot choose the appropriate actions. Many open issues remain, both in information content and form for diagnostic information.

Response Generation. In determining information requirements for the flight crew to decide how to respond to a failure, there are several factors to consider. One is that routine faults differ from novel faults, and the generation of a response is correspondingly different. Another is that responses must be made relative to the mission, goals and functions being performed by the flight crew.

Currently, flight crews have standardized procedures in the form of checklists to respond to routine faults. Until recently, these checklists have been in paper form, and the pilots retrieve them as appropriate based on the identification of the fault. In some of the new generation aircraft, these checklists are implemented electronically, so that they can be called up on a digital display when needed, or the display may be presented automatically. Electronic checklists seem like an obvious advance in the quest towards the "paperless cockpit," but undesired effects such as pilot complacency and relinquishment of perceived authority may accompany the electronic version. Palmer and Degani (1991) examined different levels of automation in electronic checklists and found that pilots did not monitor the electronic checklist at the same level of performance as with the paper checklist, and that electronic checklist designs encouraged flight crews to not conduct their own checks. This appears to be an example of behavioral phenomena that Wiener and Curry (1980) referred to as "Primary/Secondary Task Inversion," where operators begin to rely on a backup system as a primary system.

Another concern is that checklists don't exist for every fault situation. For novel faults or multiple faults, for example, the pilot may have to figure out how to modify an existing checklist, merge two checklists, or create an entirely new set of actions appropriate for the situation. Automated aid in these situations could be extremely important, but the technology has not been available to provide it. Concepts such as Faultfinder are beginning to look at the issues involved in presenting such information.

Checklists identify actions that must be taken to directly deal with the aircraft

subsystem to correct or compensate for a fault; for example, shutting down an engine. However, responses must also compensate for the effect of the fault on other functions, such as flight control, planning and navigation. For example, how can the aircraft be controlled when hydraulics fail? Can the destination airport still be reached, or should the flight crew divert to an alternate airport? Additionally, a fault may cause a constraint on the operational limitations of the aircraft that will not affect the flight until much later. For example, a landing gear problem detected in cruise will not affect the situation until landing, but the pilot must remember that information for when it is needed.

For many of these control and navigation responses, pilots currently rely on their experience to deal with the fault. An example of such a situation occurred in the crash at Sioux City, Iowa (NTSB, 1990). In this accident, the pilots used the wing engines for pitch control, because the elevators were damaged. Information on this unusual use of the engines for controlling the aircraft is not provided as part of the on-board fault management system. However, when novel faults occur, just such an action may be appropriate. The RECORS portion of the Faultfinder concept was designed to provide aid for just these types of situations (Hudlicka, Corker, Schudy, & Baron, 1990).

All the issues we have raised in this section are related to aiding the pilot in performing fault management tasks. Clearly there are many associated open research issues. There are also research issues in the information requirements associated with working with an automated aid.

Presenting Information for Managing the Fault Management Aid

The Society for Automotive Engineers G-10 Committee on automation has listed nine categories of pressing automation concerns. Situation awareness, design of the crew interface, and the role of the pilot in automated aircraft are three of those concerns. We posit that these three areas are highly related: when casting the flight crew in the role of fault manager and the automation in the role of fault management aid, a key component of required situation awareness is automation awareness, and that awareness must be supported by the crew interface to the automated aid itself: it must provide information to help the pilot manage it.

In a workshop on flight deck automation promises and realities (Norman & Orlady, 1989), Wiener described automation that exists today as "clumsy" automation. When asked if this referred to the automation or to the interface to the automation, he replied that he did not make a distinction. The problem refers to the combination (Wiener, 1989). Norman (1991) has referred to current automation as being at "an intermediate level of intelligence that tends to maximize difficult-

ies.'' Underlying these descriptions is a dual problem-one of processing clumsiness (i.e., automation can't be intelligent in all situations until it can perform sophisticated situation assessment and pilot intent inferencing), and one of clumsy or inadequate information presentation. We would argue that automation is clumsy in its presentation of information and providing feedback about itself, not so much because of technological limitations, but more because we do not have well-defined information requirements for the effective use of intelligent automation by the flight crew. There is a substantial body of literature that could be translated into information requirements, but it has not been fully exploited by those designing the automation.

What are the information requirements in terms of the pilot's need for information to manage automated aids? An exhaustive listing is beyond the scope of this paper, but we will try to touch on some that are known, but not necessarily manifested in today's flight deck automation. These requirements apply to automated aids in general, but are relevant to the fault management aids of concern here. We will first discuss information needed to support human-computer interaction via the interface to the automation (interface information requirements), and then information the flight crew needs to be aware of what the automation is doing, how it is doing it, how well it is doing it, how reliable its output is, etc. We call this automation awareness information requirements.

Interface Information Requirements

Much work has been done on tailoring the interface for interactive systems for users with different levels of experience. A system that may be used infrequently or by novice users should provide information that assists the user in interacting with the aid. The problem is that there is a time penalty in interacting with an information system, and that penalty is increased by providing information that helps the user step through the interaction. In time-critical fault situations this is unacceptable. It is likely that for the time-critical information and phases of aircraft system faults, there will be no or little interactions required with the aid; certain information may automatically be presented. Thus the issue of presenting information to assist the user in inputting and accessing information is only pertinent to later phases of a fault management situation when more time is available and the flight crew may be looking for more in-depth information. Nonetheless, such information is critical to extracting the full potential of an informational aid.

Unless a fault management aid provides this kind of supporting information about how to interact with it, it is not much of an aid, especially to a novice user. As one becomes more experienced, much of this kind of information becomes part of one's knowledge base and the need for the aid to provide this supporting

information decreases. In the context of decision aiding on the commercial flight deck, however, it should be kept in mind that situations where an automated decision aid such as Faultfinder might be used in real-time may be rare. Therefore, unless the flight crew can get sufficient off-line familiarity with the tool in a training or practice setting, they should probably be treated as novice users; at least the design should account for this possibility, which means the burden of extra ''interface'' information such as the type described above is required.

Automation Awareness Information Requirements

Norman (1991) contends that automation does not provide adequate feedback about its operation to the pilot. Feedback includes mode annunciation, that is, an indication of what it is doing or how it is performing a given function. As a recommendation for human-computer interaction design involving intelligent automation, Malin et al. (1991) state that the active operating mode should be clearly distinguished by the user interface. While a very basic requirement, mode confusions still occur with highly automated systems. There is speculation, for example, that the recent Air Intel Airbus A-320 crash involved confusion between the pilots over what flight mode was selected (Lenorovitz, 1992). While the involved system did provide mode annunciation, the question will arise as to whether it was 'clearly distinguished'. On the MD-11, systems management, in terms of reconfiguring or compensating for systems faults, can be performed automatically or in a ''manual'' mode; it is imperative that the pilots are aware of which mode is active. Feedback about the mode of operation may not be as important for informational systems as for control systems, but one certainly needs basic information about the operating status (whether it is fully functional, partially functional, non-functional), whether the aid is waiting on pilot input, searching for data, computing or processing data, or simply cannot provide a given answer or piece of information.

In addition to mode annunciation, Norman (1991) argues that one should have continuous information by which pilots can compare the current operation of the automation to their expectations about what the operation of the automation should be. Often this kind of feedback is available from natural cues. For example, the functioning of the autothrottle system is normally reinforced with continuous visual feedback from throttle position. If that cue is eliminated, then it is imperative that some information be presented by the automation showing what the autothrottles are actually doing moment to moment. As Norman (1991) points out, several accidents and incidents, such as the 1985 China Airlines 747 loss of engine power (NTSB, 1986), were contributed to by insufficient feedback from the automation. These incidents often occur even when natural feedback cues are available (such as the position of the wheel and column as a cue to the inputs the

autopilot is making to the control surfaces). This points to an area of information presentation where advances in technology can perhaps augment rather than replace other feedback cues.

The above example deals with controlling automation, but the same concerns hold true for informational automation or automation that provides computational or planning support. Sarter and Woods (1992) describe similar problems for pilots effectively interacting with flight management systems (FMS). They conclude from their studies that a majority of problems in using the FMS result from "system opaqueness." The FMS does not provide pilots "with adequate feedback on the past, present or future system state and behavior." At best, this results in mistrust and mystique (e.g., "why did it do that?"; "it's doing its magic again"), and worst, the pilots may not use the aid, may not use it properly, or may accept the aid's output without a level of understanding of its processing that is required to assess its accuracy. Making the operation of automation "transparent" certainly applies to fault management aids.

The "transparency of operation" requirement becomes even more important with "intelligent" automation which may be reasoning and hypothesizing, and supplying probabilistic or evidential information, which the human operators must then evaluate. Malin et al. (1991) discuss problems such as "providing visibility into intelligent system reasoning," "distinguishing hypotheses from facts," and "understanding intelligent system reasoning strategy." Information about reasoning processes and strategies, how the information was computed, what data it was based on, etc., is important for the pilot to have to perform the necessary evaluation of the system's output.

This is related to the second part of the clumsy automation problem alluded to above. That is, the sophistication of today's generation of intelligent decision aids is such that the aids can not be expected to perform requisite processing perfectly or provide definitive answers for all circumstances and situations. This characteristic again points to the flight crew requirement for information about the accuracy of the automation's output under different sets of circumstances. Wheeler, Bolton & Sanquist (1991), for example, suggest that one of the most demanding and difficult aspects of emergency management is evaluating the validity, timeliness, completeness and factuality of information. Pilots thus need information on an aid's overall reliability, its capabilities and limitations, when those capabilities are most useful, and when the limitations are most likely to manifest themselves. If, for example, pilots know that the TCAS has a limitation in that it cannot account for the intention of the target aircraft (e.g., whether it plans to level off or continue to descend), they may be better able to evaluate whether the TCAS advisory is a "false alarm" because they will be more likely to have acquired additional information about the intentions of the target aircraft.

In this vein, a fault management aid which assists with detection, diagnosis, and compensatory actions runs the risks of providing misinformation. In signal detection terms, the aid can have misses or false alarms. Misses are when the aid does not detect a fault or failure, or does not diagnose the correct cause. False alarms are said to occur when the aid indicates something is wrong when it is not. If the flight crew can evaluate the output of the aid based on an understanding of how it operates, its strengths and limitations, as well as on the basis of other, uncorrelated sources of information, then the fault management aid's misses and false alarms are less likely to become the pilot's misses and false alarms. The flight crew will not be as prone to extremes in reliance, either ignoring or turning the system off or over-relying on the system. The output can be evaluated and combined with other evidence relevant to the fault situation. This seems to typify the appropriate human-automation relationship for a human-centered automation approach, and the success of this relationship hinges on the operator having information by which he or she can evaluate the automation.

Integration of the Fault Management Aid Into the Flight Deck

As our final major point, note that the preceding discussion of information requirements for fault management aiding did not consider the rest of the flight deck systems of which this aid must be a part. A major concern in the design of any new automation must be the integration of the concept into the overall system of which it will be a part. For a flight deck aid, integration into both the flight deck as a whole, and the airspace system where Air Traffic Control interacts with the aircraft, must be considered. Without explicit consideration of integration, a concept might be internally consistent, but might be inconsistent when considered in an overall system context. That is, the whole might be less than the sum of the parts.

This should be of particular concern for a fault management aid, since there are other alerting systems on the flight deck now (such as, TCAS), and more are expected in the future (such as, wind shear alerting systems). We believe it is important, for example, to have a consistent alerting philosophy across all alerting systems in the flight deck, so that the flight crew does not have to interpret an alert differently depending on what system it is.

Summary

This paper emphasized information content, that is, what information should be presented for management of aircraft systems faults, and additionally, when

it should be presented. In that context, this paper focused on information to support fault management performed by the flight crews of commercial aircraft flight decks. We discussed the characteristics of the application, and the similarities to and differences from fault management in other application areas. We discussed human management of faults using automation as an aid, and how this human-centered automation philosophy affects the design of the decision aid. We discussed the importance of determining the appropriate role of the human, and the determination of information requirements. The results of studies addressing the information needs and desires of flight crews were described, with a particular emphasis on the manner in which the pilots process the information to support fault management tasks. In addition to discussing presentation of information for managing failures, we also described the need to present information to manage the fault management aid. Lastly, we raised the issue of integrating the fault management aid with the remainder of the flight deck systems.

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Plasmon Excitation in Conducting Solids

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ABSTRACT

Drude model fits to the dielectric functions of 15 metals are available, largely based on the experimental work of Ordal and collaborators. The resulting values of plasma and damping frequencies provide predictions for the DC conductivity in reasonable agreement with measured data, and they also permit (approximate) predictions for the dielectric constant ε_1 [the $\omega \to 0$ limit of the real part of the DC dielectric function $\varepsilon(\omega)$] of these metals, which is found to be large and negative. More accurate values for this and the plasma frequencies can be based on empirical tabulations, and with the usual interpretation of the crossover of $\varepsilon_1(\omega)$ from negative to positive values near the optical region as corresponding to plasmon excitation, these values allow the calculation of electron loss factors which are sharply peaked close to the plasma frequency. A trend of the DC conductivity to rise with increasing plasma frequency is pointed out, and this trend can also be followed through in the direction of decreasing conductivity, as is shown here for several poor conductors (carbon and conducting polymers).

Introduction

In a series of studies, Ordal et al. (1985; 1987; 1988) have carried out electromagnetic power reflectance measurements on various metals in the $1/\lambda = 180 \leftrightarrow 50{,}000\ \mathrm{cm}^{-1}$ range, as well as absorptance measurements using a nonresonant cavity in the $30 \leftrightarrow 300\ \mathrm{cm}^{-1}$ range. Combining these data in the far-IR, IR and visible region with those found by others, they were able to obtain, using Kramers-

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Kronig analysis of their surface-impedance data, the real and imaginary parts of the dielectric function,

$$\varepsilon(\omega) = \varepsilon_1(\omega) + i\varepsilon_2(\omega), \tag{1}$$

as functions of frequency in the mentioned frequency range. Subjecting these results to a Drude model (see, e.g., Bohren & Huffman, 1983) two-parameter fit (parameters being the plasma frequency ω_p and the damping frequency ω_τ, reasonable fits were obtained which can be used to extrapolate $\varepsilon(\omega)$ down to its DC value $\varepsilon(0)$. In this way, Ordal et al. (1985) found DC conductivity values $\sigma(0)$ which generally compared well with conventionally-measured and tabulated (Babiskin & Anderson, 1972) conductivities.

By combining the various Ordal data (Ordal et al., 1985; 1987; 1988) and the Drude model fits, we tabulate the DC conductivities and also the previously believed (Slater & Frank, 1947) unmeasurable DC dielectric constants for fifteenmetals, by extrapolation of the Drude model fits to low frequencies. We note that DC conductivities exhibit a rising trend as the plasma frequency increases, and we show that such a trend also holds for a few poor conductors considered here (carbon and conducting polymers).

As a further step, we tabulate the crossover-frequencies ω_o of these metals at which $\varepsilon_1(\omega)$ changes sign; at this place, the electromagnetic field is longitudinal (Bohren & Huffman, 1983) corresponding to a collective longitudinal oscillation of the free electrons known as a plasma oscillation (in quantized form, a plasmon). For the metals considered here, the values of ω_o lie in the visible ($1/\lambda \sim 1.4 \times 10^4 - 2.5 \times 10^{-4}$ cm^{-1}) or ultraviolet region. It should be emphasized that the Drude model equations given below only contain the effects of the free electron gas, neglecting the effects of bound electrons and/or of ionic vibrations on the dielectric function. These resonance effects have been discussed at length (see, e.g., Bohren & Huffman, 1983) and are illustrated there e.g. in Fig. 9.11, they appear close to the visible region and can be noticed in Ordal's data which are presented on logarithmic plots. The resonance effects differ for individual materials, so that no general statements can be made about them. As to our use of the Drude fits to predict plasmon excitation frequencies, it could be argued that the free-electron plasmon is screened by the dielectric constant at optical frequencies, causing shifts in ω_o.

Tabulations of earlier reflectivity and absorptivity data (Weaver et al., 1981) do include these effects, as well as the above mentioned resonance effects, on the dielectric function in an empirical fashion, and alternate (empirical) values of ω_o and $\varepsilon_1(0)$ can be obtained from Weaver et al. (1981), indeed leading often to differences with the Drude values. For purposes of determining plasmon frequencies, the empirical values should be preferable. Likewise, loss factors for

the excitation of plasmons by electron scattering, sharply peaked about the crossover frequencies, are obtained from the empirical data (Weaver et al., 1981) together with their widths.

Drude Model Fits to the Optical Properties of Metals

The Drude model was proposed in 1904 and is the earliest realistic model for a metal (see, e.g., Pines, 1964; Peierls, 1956). It has often been quoted as offering a surprisingly good description of the optical properties of metals, considering the crudity of its assumptions, and even the introduction of quantum theory with its Fermi-gas picture of conduction electrons (Sommerfeld & Bethe, 1933), did not change its results except explain the origin of its frictional resistive force (Slater & Frank, 1947; Peierls, 1956). This frictional force introduces a mean collision time τ for each electron, and the electron current density becomes in a harmonically time-varying field $\vec{E} \propto \exp(i\omega t)$:

$$\vec{j} = \sigma(\omega)(\vec{E} - \tau\delta\vec{E}/\delta t) \tag{2}$$

Where the component of $\vec{j}$ proportional to $\vec{E}$ is the conduction current, with the coefficient of proportionality being the effective conductivity at frequency ω:

$$\sigma(\omega) = \sigma_o/(1 + \omega^2\tau^2) \tag{3}$$

where $\sigma_o = ne^2\tau/m^*$ is the DC conductivity (n = electron density, m* = electron effective mass). The component of $\vec{j}$ proportional to the time rate of change of $\vec{E}$, and hence cut of phase with it, is physically equivalent to the displacement current arising from the dieloectric constanct.

In place of σ and ε_1, the complex dielectric function $\varepsilon(\omega)$ of Eq. (1) may be employed where ε_2 contains the effects of conductivity. The Drude model gives for it (Ordal et al., 1985) the expressions

$$\varepsilon_1 = 1 - \omega_p^2/(\omega^2 + \omega_\tau^2), \tag{4}$$

$$\varepsilon_2 = \omega_\tau\omega_p^2/[\omega(\omega^2 + \omega_\tau^2)]. \tag{5}$$

The two parameter contained therein are, in corresponding units, the plasma frequency

$$\omega_p = (4\pi ne^2/m^*)^{1/2}/(2\pi c) \tag{6a}$$

and the damping frequency

$$\omega_\tau = {}^1/(2\ \pi c\ \tau). \tag{6b}$$

Using Eq. (5), the DC value of the conductivity may be obtained in terms of ω_p

and ω_τ, and shall thus be referred to (Ordal et al., 1985) as the "optical frequency" conductivity (units cm^{-1}),

$$\sigma_{opt} = \omega_p{}^2/(4\pi\omega_\tau), \tag{7}$$

to distinguish it from the standard conductivity σ_o as measured in DC experiments. The assumed validity of the Drude model should then lead to an agreement of σ_{opt} with σ_o, which will be seen below to be generally the case, except for some individual deviations.

Table I collects results of Ordal et al. (1985; 1987; 1988), listing the Drude fit parameters ω_p and ω_τ as well as the empirically determined values (Weaver et al., 1981) for ω_p, and empirical values for ω_τ to be discussed below. The table also lists the DC resistivities ρ_o and ρ_{opt} (based on the Drude model), the latter being related to the conductivities by

$$\sigma_{o,opt}(cm^{-1}) = 9*10^{11}/(2\pi c[\rho_{o,opt}(\Omega cm)]). \tag{8}$$

The ratio ρ_o/ρ_{opt} is seen to be generally close to unity, but it shows individual differences as mentioned. We complete the table by also listing the DC dielectric constant $\varepsilon_1(0)$, given in the Drude model by

$$\varepsilon_1(0) = 1 - \omega_p{}^2/\omega_\tau{}^2, \tag{9}$$

thus providing the values of the dielectric constant ε_1 for metals. These should be considered as approximations only, and in fact we also tabulate empirical values of $\varepsilon_1(0)$ following from Weaver et al. (1981) by extrapolation to $\omega \to 0$. Such an extrapolation is fraught with great uncertainties, and the large differences with the Drude values could be due to uncertainties both in the Drude fits or in this extrapolation. The "empirical" values for ω_τ are obtained from those of $\varepsilon_1(0)$ via Eq. (9).

As Eq. (4) shows, the function $\varepsilon_1(\omega)$ increases monotonically from the large negative DC values displayed in Table I to the value of unity at infinite frequency, passing through zero in the vicinity of the optical range. On the other hand, Eqs. (3) and (7) show that $\sigma(\omega)$ decreases monotonically with increasing frequency. This behavior is shown in Fig. 1 and is characteristic of plasma or collective oscillations in a solid, resulting from the high density of electrons present in a metal and the fact that they can act cooperatively due to the Coulomb interaction among them.

The energy of these oscillations is large compared to the single-particle energy because a plasma oscillation at long wavelengths involves the correlated motion of a very large number of electrons. No single electron is greatly perturbed but, because a large number of electrons are moving together in a coherent fashion, the resultant energy of the collective mode is quite substantial.

Table I.—Drude model and empirical fits for optical constants and resistivities of 15 metals

	ω_p (cm^{-1})		ω_τ (cm^{-1})	$-\epsilon_1$ (0)	ω_τ (cm^{-1})	$-\epsilon_1$ (0)			
Metal	Drude	empir.[e]	Drude		empir.[e]		ρ_o[a] ($\mu\Omega$cm)	ρ^{opt} ($\mu\Omega$cm)	ρ_o/ρ_{opt}
Ti[b]	20,300	3,600	382	2,823	66	3,000	43.1	55.62	0.775
W[b]	51,700	10,700	487	11,270	74	21,000	5.33	10.93	0.488
Mo[b]	60,200	11,700	412	21,350	55	45,000	5.33	6.82	0.781
Ta[c]	66,200	16,400	704	8,841	110	22,000	13.1	9.64	1.359
Ag[b]	72,700	30,200	145	251,380	114	70,000	1.61	1.65	0.978
Au[b]	72,800	46,600	215	114,650	170	75,000	2.20	2.43	0.904
Pt[b]	41,500	48,800	558	5,530	583	7,000	10.42	19.44	0.536
V[b]	41,600	53,700	489	7,236	600	8,000	19.9	16.95	1.174
Pb[d]	59,400	–	1175	2,555	–	–	21.0	19.98	1.051
Pd[b]	44,000	62,300	124	125,910	279	50,000	10.55	3.84	2.745
Co[b]	32,000	64,900	295	11,770	684	9,000	5.80	17.29	0.336
Cu[b]	59,600	64,900	73	662,900	530	15,000	1.70	1.24	1.375
Ni[d]	39,400	75,800	178	48,990	580	17,000	7.04	6.88	1.023
Fe[c]	29,500	85,500	156	35,760	927	8,500	9.80	10.76	0.911
Al[c]	95,400	121,400	424	50,624	303	160,000	2.74	2.80	0.980

[a] Babiskin & Anderson (1972), pp. 9–39, 9–40.
[b] Ordal et al. (1985), p. 4494
[c] Ordal et al. (1988), pp. 1205–1207
[d] Ordal et al. (1987), p. 747 (all for Drude case)
[e] Weaver et al. (1981).

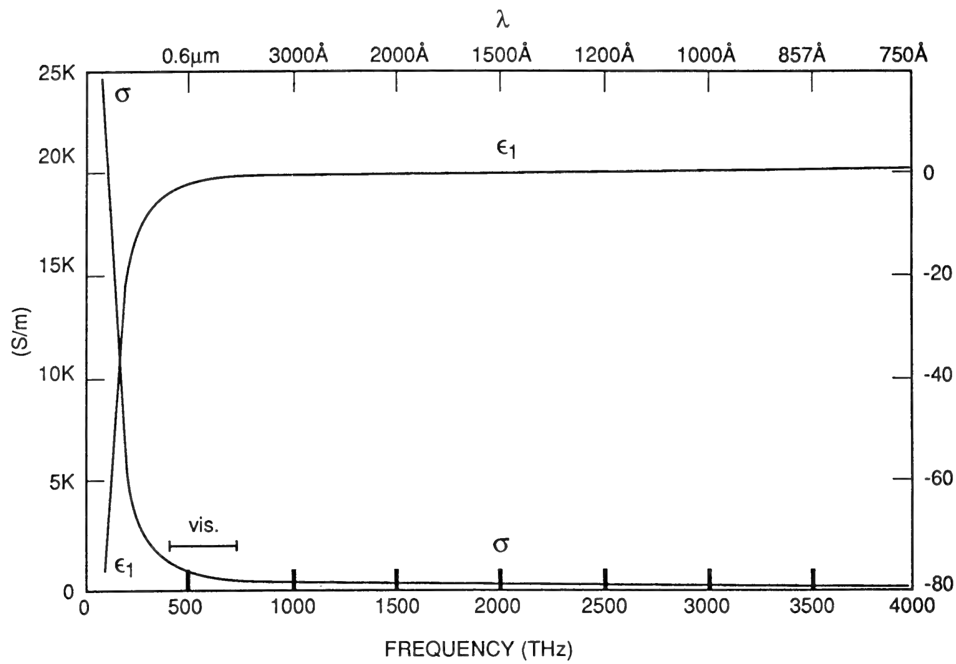

Fig. 1. Drude-fit values of and ε for Fe as functions of λ and frequency (THz).

Electrons, Plasmons, and Photons in Solids

Drude completely neglected the ionic cores present in solids and the fact that electrons obey Fermi statistics. Pines provides a much more complete treatment, including the effects of the periodic lattice, photons, electron-electron and electron-phonon interactions, and plasmons (Pines, 1964). The plasmon is the quantum of plasma oscillation energy. Electron interactions in solids differ from those in a free-electron gas, because changes in screening behavior due to the periodic ion potential influence the plasmon spectra. Plasmons are bosons, and have a distribution function of the characteristic boson form at finite temperatures.

Under certain conditions plasma oscillations represent normal modes of the entire system, which means that once such oscillations are excited, they do not decay in time. Since they maintain themselves, we would expect to find an internal electric field $E(\omega_p)$ in the solid at the plasma frequency ω_p, due to the oscillations in the electron density, without the presence of an external field $D(\omega_p)$. By the constitutive relation, since

$$D(\omega_p) = \varepsilon(\omega_p)E(\omega_p) = 0 \tag{10}$$

and $E(\omega_p) \neq 0$, the condition for plasma oscillations is therefore

$$\varepsilon(\omega_p) \equiv \varepsilon_1(\omega_p) + i\varepsilon_2(\omega_p) = 0. \tag{11}$$

Table II.—Imaginary part of the dielectric function ϵ_{20}, loss factor and half width $\Delta\omega_o$ at the (empirical) plasmon resonance frequency ω_o. Also, DC conductivities (Drude model)

Metal	$\omega_o=\omega_p$ (cm^{-1})	f_o (THz)	$\hbar\omega_o$ (eV)	ϵ_{20}	Loss Factor	$\Delta\omega_o$ (cm^{-1})	σ_o (10^8S/m)	σ_{opt} (10^8S/m)
Ti	3600	108	0.45	21.75	0.046	66	0.023	0.018
W	10700	321	1.33	19.80	0.051	74	0.188	0.091
Mo	11700	351	1.45	22.35	0.045	55	0.188	0.145
Ta	16400	492	2.03	7.46	0.134	110	0.076	0.104
Ag	30200	906	3.75	0.44	2.273	114	0.621	0.606
Au	46600	1,400	5.78	2.90	0.345	170	0.455	0.412
Pt	48800	1,460	6.05	3.82	0.262	583	0.096	0.051
V	53700	1,610	6.66	1.87	0.535	600	0.050	0.059
Pb	59400	1,780	7.37	0.02	50.54	1175	0.048	0.050
Pd	62300	1,870	7.72	1.32	0.758	279	0.095	0.260
Co	64900	1,950	8.05	2.06	0.485	684	0.172	0.058
Cu	64900	1,950	8.05	2.10	0.476	530	0.588	0.808
Ni	75800	2,270	9.40	1.83	0.546	580	0.142	0.145
Fe	85500	2,560	10.60	1.54	0.649	927	0.102	0.093
Al	121400	3,640	15.06	0.04	26.32	303	0.365	0.357

Thus, strictly speaking, plasma oscillations should exist as normal modes of the system only if both real and imaginary parts of the dielectric constant vanish at ω_p. In practice, however, plasma oscillations will exist if $\varepsilon_2(\omega_p) \ll 1$ when $\varepsilon_1(\omega_p) = 0$. Since ε_2 represents the damping of the plasma resonance, the condition $\varepsilon_2(\omega_p) \ll 1$ implies damping should be small.

More precisely, when plasma oscillations are damped, the frequency at which $\varepsilon_1(\omega) = 0$ does not quite provide us with plasmon energy. By Eq. (4), the real part of the dielectric function vanishes at the frequency ω_o, where

$$\omega_o^2 = \omega_p^2 - \omega_\tau^2$$

Because $\omega_\tau/\omega_p \ll 1$, ω_o is very nearly equal to ω_p. Values of ω_o in cm^{-1}, simply approximated by the (empirical) values of ω_p of Table I, are given in Table II, along with the equivalent frequency f_o in THz and the corresponding photon energy in eV for 15 metals. Table II also gives $\varepsilon_{20} \equiv \varepsilon_2(\omega_o)$ the value of the imaginary part of the dielectric function at ω_o from the empirical data of Weaver et al. (1981).

The principal experimental evidence for the existence of plasmons as a well-defined excitation mode of the valence electrons in solids comes from characteristic energy-loss experiments, where one observes the energy spectrum of kilovolt electrons, either as they emerge from a thin solid film or after they are reflected from a solid surface (Peierls, 1956). In fact, the most familiar method of determining ω_p utilizes measurement of these characteristic electron energy losses, which are proportional to the "loss factor" $-\operatorname{Im}(1/\varepsilon(\omega))$, a function of width $\Delta\omega_o = \omega_\tau$ that is very sharply peaked about ω_o when the conditions for plasma oscilla-

tions are fulfilled (Daniels et al., 1970). When one measures the angular distribution of the inelastically scattered electrons, one measures $\mathrm{Im}(1/\varepsilon(\omega))$ directly for the electrons in the solid.

Whereas fast electron scattering is a longitudinal probe of the solid, in which the electron gas responds to a time-varying longitudinal field, measurements of the optical reflectivity of a solid constitute a transverse probe of the solid, because the electromagnetic wave couples directly to the transverse current-density fluctuations of the electrons. Therefore, the dielectric constant is a tensorial quantity because, just as the response of the electron gas to a time-varying longitudinal field defines a longitudinal dieletric constant, the system response to an external electromagnetic field defines a transverse dielectric constant.

Pines (1964) presents a comparison of the optical values of plasmon energies for the alkali metals, based on reflection experiments, with the values measured in electron energy-loss experiments and remarks that agreement between the two methods is quite good. Experiments have been made to compare the electron energy loss function with that calculated from known optical constants. General agreement has been found in the detailed structure of the two loss functions (Daniels et al., 1970), so no experimental evidence exists to date for a difference between the two dielectric functions.

Values of the loss factor, $-\mathrm{Im}(1/\varepsilon_1(\omega))$, from the empirical tabulation of Weaver et al. (1981) are given in Table II and exhibited for 14 metals (except for Pb where only Drude values exist) as a function of f_o and λ in Fig. 2. Also entered in Table II, for the purpose of later discussion, are the values of σ_o and σ_{opt} in units of 10^8 S/m (1 Siemens = S = Ω^{-1}), obtained from the Drude values of Table I via Eq. (8).

Scattering of Electromagnetic Waves

The behavior of the dielectric constant in a region of appreciable conductivity has a profound effect on the scattering of electromagnetic waves from metals. If one considers scattering from a simple model of a solid with $\varepsilon \equiv 1$ and σ equal to its constant DC value, the reflection coefficient gradually decreases from unity with increasing frequency, as shown in Fig. 3, in accordance with the familiar Hagen-Rubens relation discussed by Born and Wolf (1975). Schumacher (1987) has provided an explanation of the scaling laws that require σ to increase with increasing frequency for the reflection coefficient to remain constant.

Even though the Drude σ decreases with increasing frequency in accordance with Fig. 1, which by itself would lead to a reflection coefficient decreasing from unity with increasing frequency more rapidly than the simple solid model shown

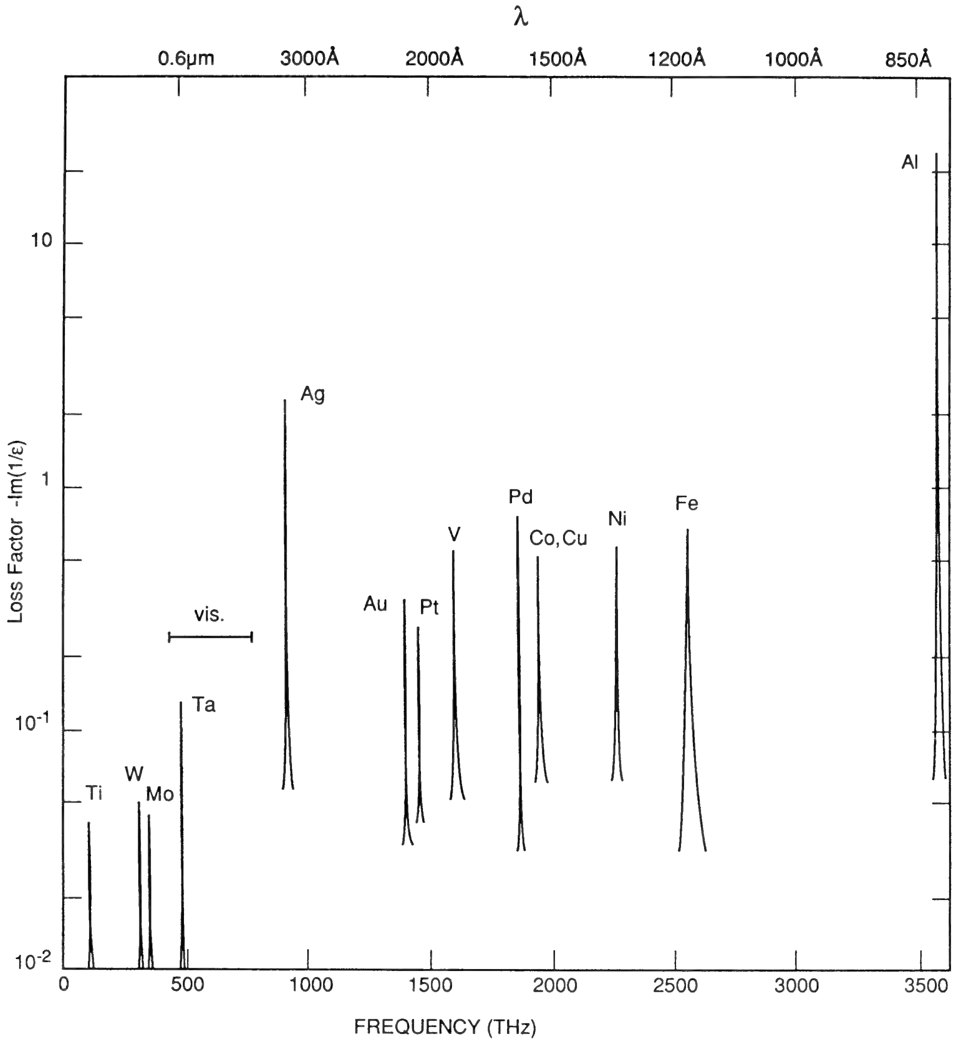

Fig. 2. Values of the loss factor ≡ $-\mathrm{Im}(1/\varepsilon)$ for 14 metals as a function of f_o and λ.

in Fig. 3, the strongly negative Drude (or empirical) ε_1 causes a large impedance discontinuity, which keeps the reflection coefficient very nearly equal to unity until it drops very rapidly at the plasma resonance frequency to values far below those of the simple solid model.

This finding has very significant practical consequences. Usually infinite σ is assumed for the metals used in radar calculations, even though one expects eventual decreases in the reflection coefficient of physical scale models caused by the polarization not being able to keep up with exciting electromagnetic fields as the measurement frequency increases. In fact, scaling laws require that σ

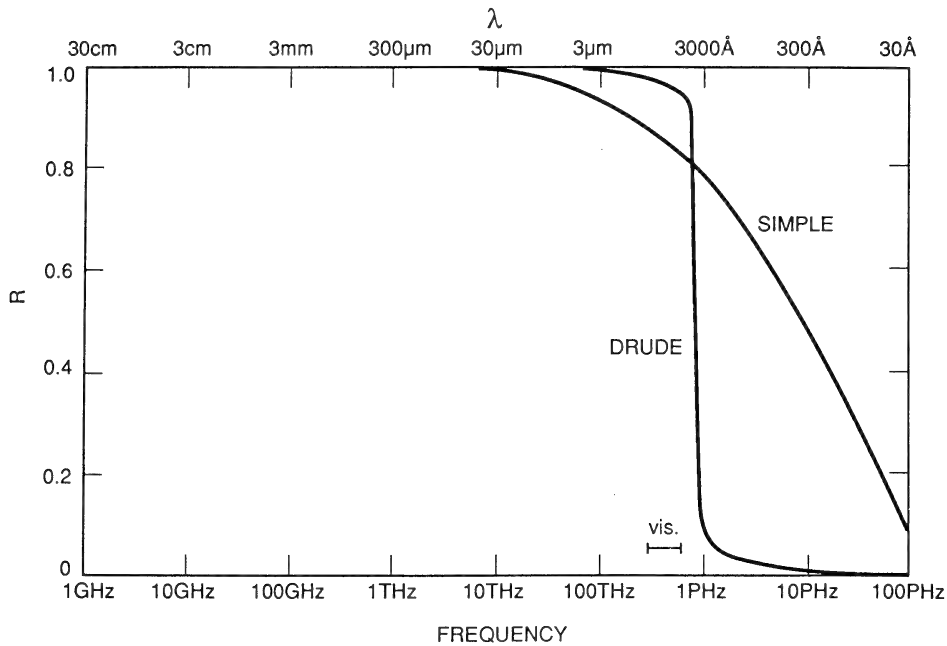

Fig. 3. Values of R, the reflection coefficient for power, as a function of frequency and λ for the Drude theory and for a simple solid modele with the DC value of σ and $\varepsilon \equiv 1$ for the case of Fe.

increase to very large unphysical values in the IR range for the reflection coefficient to remain constant (Schumacher, 1987).

However, our theoretical study of plasmon excitation in good conductors yields the same reflection effect as a σ actually increasing with frequency in the physical scale modeling range, but finally decreasing to zero as photon energies reach the electron volt range, in accordance with Fig. 3. Thus, not only is the assumption of infinite σ fully justified in physical scale model measurements, but also there is a new understanding of the reflection properties of metallic scale models.

The above results also have implications for radar absorbing materials. An ideal absorber is one that allows incident electromagnetic energy to enter without reflection and then to rapidly attenuate over a short distance. However, it does not appear possible to satisfy these two conditions simultaneously. Undoubtedly, attenuation is rapid if both electric and magnetic losses are high. However, these losses are related to imaginary components of the dielectric and magnetic polarization, both of which result in reflection.

DC Conductivity vs. Resonance Frequency: Good and Poor Conductors

In Fig. 4, we present a graph of σ_o (crosses) and σ_{opt} (circles), from Table II, plotted vs. the resonance frequencies of the 15 metals considered here. A trend

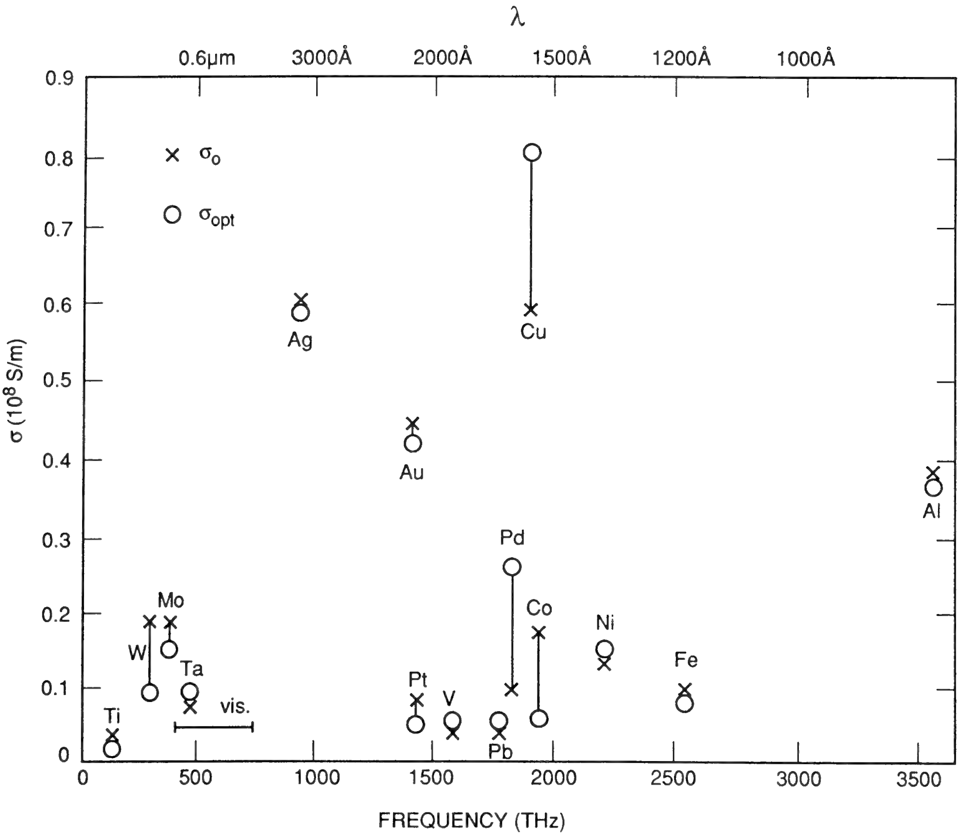

Fig. 4. Values of DC conductivities σ_o and σ_{opt} for 15 metals from the Drude model, at the emperical resonancs frequencies.

of increasing DC conductivity with rising frequency is readily apparent here. Such a trend can already be discerned from Eqs. (7) and (12), and the deviations of σ_{opt} from a smooth curve are caused by the scattering of the ω_τ values as seen in Table I.

Here, the opportunity arises of extending our present study from solely good conductors to also including some poor conductors, such as carbon (graphite) and two conducting polymers, for which the resonance frequencies are believed to be known. In Table III, we list the values of f_o(THz) for the conducting polymer poly[bis-(3-ethynylaniline)-N,N′-(1,4-dimethylydene)] pyrolyzed at 500° C, the same sample pyrolyzed at 700° C, and for graphite. These resonance frequencies were determined by use of a Hewlett-Packard 4191A impedance analyzer. The DC conductivities were measured for the polymer by use of a Simpson 260 multimeter and for carbon, σ_o was taken from Babiskin & Anderson (1972). Also included in Table III are the first metal of Table II (Ti), the last metal (Al), and

that with the highest conductivity (Cu), for purposes of comparison. The same data are shown graphically in Fig. 5, on a double-logarithmic plot. It is seen here that by including poor conductors, the (semi-empirical) downward trend of DC conductivity with decreasing resonance frequency f_o, noted before for metals in Fig. 4, has now been (empirically) extended further for poor conductors by many decades. It would, of course, be possible to try describing these poor conductors by the Drude model also. In that case, one would find from Eq. (7) the values of the damping frequency $\omega_\tau = 6.94\ cm^{-1}$ (C), $7.4 \times 10^{-7}\ cm^{-1}$ (Pyr. 700°), and 6.7×10^{-2} (Pyr. 500°); but this would (except for C) probably amount to pushing the Drude model too far, in view of the large jumps between Pyr. 500° and Pyr. 700°. Nevertheless, the continuing trend of DC conductivities over many decades for good and poor conductors remains an interesting feature.

Conclusions

Approximate numbers for the static values of the dielctric constant, $\varepsilon_1 \equiv \varepsilon_1(0)$, of 15 metals have been obtained from experimental data, both via Drude fits or purely empirically. All these DC values are shown to be negative and very large. Higher frequency values of ε_1 increase monotonically with increasing frequency passing through zero in the optical range between wavelengths of 1000 and 6000 Ångströms. This frequency dependence of ε is obtained from values of plasma and damping frequencies reported by Ordal et al. (1985; 1987; 1988), which were derived from Drude model fits to the Kramers-Kronig analysis of a combination of their new infrared measurements of the optical constants of 15 metals and other previous measurements. It is also obtained empirically (Weaver et al., 1981) from earlier data.

Ordal's Drude-model fits predict values of the conductivity, σ, that decrease monotonically with increasing frequency but are in good agreement with measured static values. This behavior is characteristic of plasma or collective oscillations in a solid and is interpreted as plasmon excitation. Very sharply peaked loss factors are tabulated for 14 metals. This behavior of ε causes a large impedance

Table III.—Resonance frequencies of several poor and good conductors

Substance	f_o (THz)	σ_o (10^8 S/m)	σ_{opt} (10^8 S/m)
Pyr.500°C	6×10^{-6}	1×10^{-14}	–
Pyr.700°C	2×10^{-4}	1×10^{-6}	–
C	16.5	0.727×10^{-3}	–
Ti	108.0	0.0232	0.018
Cu	1,950.0	0.588	0.808
Al	3,640.0	0.365	0.357

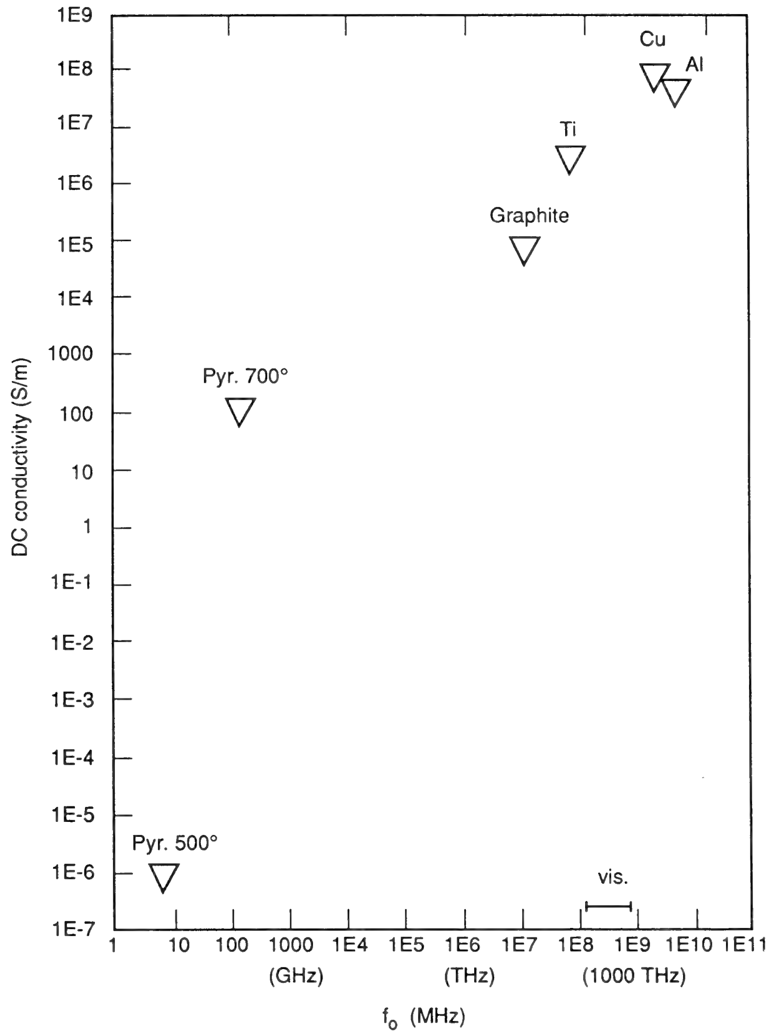

Fig. 5. Values of DC conductivities σ_o for three poor conductors and three metals.

discontinuity, which keeps the reflection coefficient very nearly equal to unity until it drops very rapidly at the plasma resonance frequency to values approaching zero as photon energies reach the electron volt range. This behavior is compared to scattering from a simple model of a solid with $\varepsilon = 1$ and σ equal to its constant DC value, which yields a reflection coefficient decreasing more slowly with increasing frequency, in accordance with the familiar Hagen-Rubens relation.

A trend of the DC conductivity to increase with rising plasma resonance frequency is noted for the 15 metals under consideration. This trend, which is

semiempirical on the basis of the Drude model, is empirically extrapolated downwards by including a few poor conductors (carbon and conducting polymers), and is seen to persist here over many decades.

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Cognitive Complexity, Conceptual Systems, and Behavior

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ABSTRACT

Historical findings concerning the nature of the higher-order structural personality dimension of cognitive complexity and related conceptual systems, including systematic effects on moral reasoning and behavioral style, are summarized. The author's own research on early trainer and traumatic event effects on one's complexity level; and the effect of individual differences in cognitive complexity on creativity, leader behavior and influence, interpersonal and self perception, group task performance, and matching individual and position complexity are reviewed. The author's use of the cognitive complexity dimension in organizational assessment and design is described.

During the past three decades, there has been a growing body of research, largely outside the fields of engineering psychology and ergonomics, which I believe to be relevant to our understanding of individual differences in human performance, including values, attitudes, motives, creativity, and stylistic leadership and work behavior. This research concerns the higher-order structural personality dimension of cognitive complexity, or concreteness-abstractness of thinking. The fact that the high technology societies of the world appear to be undergoing significant, yet understandable age-related demographic changes in this higher-order personality dimension further enhances its value to us in understanding human performance.

This area of structured personality research had it origins in the classical work of Piaget (1948) on child development. Among others, two groups of researchers of particular relevance to this paper have extended the study of concreteness-abstractness into the adult range. These are O.J. Harvey, D. E. Hunt, and H. Schroder (1961) in the area of conceptual functioning or conceptual systems and behavior, and Lawrence Kohlberg and his colleagues at Harvard with respect to the structure of moral reasoning (1969).

Cognitive complexity, or concreteness-abstractness is reported to have two major structural aspects, differentiation and integration (Harvey, et al., 1961). Operationally, differentiation can be defined as the number of dimensions extracted from a set of data, and integration as the number of interconnections between rules for combining structured data (Barrif and Lusk, 1971). A concrete cognitive style is one in which relatively little differentiation is used in structuring concepts. Experiential data are categorized by the individual into relatively few conceptual dimensions, and within concepts, there exists relatively few categories or shades of grey. In the extreme, a concept is divided into just two categories, characteristic of either/or, black/white, absolutist thinking. In addition, concrete thinkers are relatively poor at integrating conceptual data in assessing complex problems and developing unique or creative, insightful solutions. In contrast, cognitively complex persons tend to demonstrate high differentiation and effective integration in their conceptualizing (Harvey, 1966; Harvey, et al., 1961).

Although all persons tend to become more abstract over time, our development curve tends to flatten in early adulthood. At what degree of cognitive complexity this plateauing occurs appears to depend primarily on two factors: How open one is to learning from one's experience, and how much exposure one has had to diversity. We all start out in life with very limited exposure to diversity, and thus have few conceptual categories in which to place experiential information, and few rules and combinations of rules to integrate our experiential information. As we gain new experiences, and if we are open to learning from those experiences, we develop new conceptual categories and more rules and rule combinations for integrating our conceptual data (Harvey, 1966). How open we are to learning from our experiences depends on the nature of one's early training environment at home and school (Blatt, 1971). In particular, the nature of the "trainer" role appears to be critical. In general, the more absolutist and authoritarian the parent, teacher or other trainer, the greater is the likelihood that active exposure was inhibited, and that the child will plateau at a relatively concrete level of conceptual functioning (Harvey, et al., 1961). The more relativistic and less authoritarian the training, the more the trainer encourages the child to think things through and draw personal conclusions, and the more the trainer instills a strong positive sense of self worth in the child, the more abstract or cognitively complex the child will become in his or her conceptual functioning as an adult.

Cognitive Complexity and Moral Reasoning

When Lawrence Kohlberg set out to study moral reasoning, he was looking for structures, forms and relationships that are common to all societies and languages (Kohlberg, 1969). Over the years, he gradually elaborated a topological scheme

for describing the general structure and forms of moral reasoning that he and his colleagues had found throughout the world. Of particular importance was the finding that moral reasoning could be defined independently of the specific moral content of moral decisions and actions. Kohlberg found that their were three different developmental levels of moral reasoning that lie along the concreteness-abstractness dimension. At any given point in one's life, the rationale underlying a large majority of one's moral decisions will be at a single level. Each level of moral reasoning appears to have two variations or stages (Kohlberg, 1969).

Level 1: Preconventional Moral Reasoning

This level is characteristic of highly concrete functioning. It is oriented around concepts of good and bad which are interpreted in terms of physical concepts (punishment and reward) or in terms of the physical power of those who make the rules (i.e., might is right). Within the preconventional level are two discernable stages. Stage 1 is an orientation toward punishment and unquestioning deference to superior power. Here a good decision is one which leads to avoidance of punishment. Stage 2 is an orientation toward personal need satisfaction and, occasionally, the needs of others. Elements of fairness, sharing and reciprocity are present, but it is a "you scratch my back and I'll scratch yours" kind, rather than a reciprocity based on loyalty or justice. This stage sometimes is referred to as the morality of the marketplace.

Level 2: Conventional Moral Reasoning

This level can be described as conformist in the sense of maintaining the expectations and rules of one's family, group, culture or nation. The maintenance of existing ways is perceived as a valuable end in and of itself. Stage 3 is referred to as the good-boy, good girl orientation. Here, the goodness of an action is based on whether it pleases or helps others and is approved by them. Stage 4 is an orientation towards authority, fixed rules, regulations, and the maintenance of the existing social order. The goodness or rightness of behavior is judged on the extent to which a person is doing one's duty, showing respect for authority, and maintaining the existing order as an end in itself; it is a reliance on external sources for ones moral decisions.

Level 3: Postconventional Moral Reasoning

The postconventional level reflects cognitively complex or abstract functioning. It is characterized by autonomous, universal moral principles, which provide an internalized and more principled moral basis for one's decisions. Stage 5 is a social contract orientation with legalistic overtones. The rightness of an action tends to be evaluated in terms of respecting the general individual rights of

persons, and the standards which have been critically examined and agreed upon by the whole society. Stage five is the ''official'' morality of the American government and the U.S. Constitution. Stage 6 is an orientation of universal moral and ethical principles. Morality is not defined by a given society, but by one's conscience in accordance with self-determined moral principles. These are not concrete rules like the Ten Commandments; rather, they are broad and abstract and include universal principles of justice and the reciprocity and equality of human rights.

Cognitive Complexity and Conceptual Systems

Based on their original research, Harvey, et al. (1961) concluded that there appear to be at least four fundamentally different ways in which people organize or structure and integrate their experiences of reality. Further, these four ways appear to lie along an invariant developmental continuum, with the underlying dimension being concreteness-abstractness or cognitive complexity. As persons develop greater differentiation and integration in their conceptual functioning, they may move on to a new, more cognitively complex way of viewing reality. These four systematic ways or stages, in order of their developmental occurrence, are labeled simply as conceptual systems 1, 2, 3, and 4. Because a given person's level of cognitive complexity can fall at any point along the continuum, it is possible to function primarily out of one conceptual orientation but secondarily out of another. While the four conceptual systems represent points along the cognitive complexity continuum, the specific location of those points can vary somewhat from person to person.

In their initial research, Harvey, et al.(1961) identified the following sets of characteristics associated with each conceptual level of functioning. Subsequent research, including that by the author, consistently has confirmed these findings.

System 1 Functioning: Conventional (Conformist) Thinking and Behavior

Regardless of culture or nationality, all persons start out with a highly concrete System 1 orientation toward reality. As persons gain experience, they become more abstract in their conceptual functioning, but still may maintain a System 1 perspective. In comparison with persons with other, more abstract, conceptual orientations, System 1 persons are characterized by conventional thinking and behavior. If highly concrete, the majority of their moral decisions are at Kohlberg's Preconventional Level. If somewhat more abstract, their moral reasoning tends to be at the Conventional Level; and they tend to rely on rules, regulations, tradition, and other external sources of ''authority'' as the basis for their decisions.

In comparison with more abstract functioning individuals, the research consistently has shown System 1 persons to have a relatively high need for (a) structure and order and (b) simplicity and consistency, to be relatively (c) authoritarian, (d) absolutist, (e) closed in their belief systems, (f) ethnocentric, (g) paternalistic (h) personally rigid, (i) have a low tolerance for ambiguity, (j) highly accepting of prevailing rules, norms, and social roles - and to see them as relatively static and unchanging, and (k) to have a high belief in external fate control.

Research, to date, suggests that approximately 60% of the American adult population is operating primarily from a System 1 perspective; but that there are systematic differences by age group. Among those who are in their late 60's or older, approximately 80% may be operating at the System 1 level. Among those in their 40's and younger, less than half are operating from a System 1 orientation. Those in their 50's and early to mid 60's represent the national average. Limited research in other industrialized countries suggests a similar pattern.

Although age related, these differences are not age caused. Rather, other factors, such as generational differences in child rearing patterns, addressed later, and amount of childhood and adolescence exposure to diversity through such things as media, education, travel, etc. appear to be the most important factors. In fact, because of experience, those in their late 60's and older are more cognitively abstract now than they were when they were young adults.

System 2 Functioning: General Negativism

As persons become more abstract, the System 1 conception of reality eventually may "break down". These individuals react by becoming focused on, and sensitized to what is "wrong" with the "system" - its institutions and persons who exercise authority and restraint over their lives. From a developmental standpoint, the individual appears to learn more about oneself as distinct from the generalized cultural standards which had been applied to both self and others during System 1 functioning (Hunt, 1966). In their moral decision-making, System 2 persons often seem in a kind of psychological vacuum. They tend to see the external norms, which heretofore they had relied upon, as having let them down and, thus, no longer reliable. As yet, they have not replaced this external basis for their decisions with an internalized, principled basis, characteristic of Postconventional moral reasoning. About all System 2 persons can do is react in a distrustful, negative manner; which Kohlberg (1969) describes as a kind of Stage 2 hedonistic relativism which is confused with more principled moral reasoning.

Like System 1 individuals, but to a lesser extent, System 2 conceptualizers tend to have a high need for structure and order and simplicity and consistency, be absolutist, closed minded, not highly creative, and personally rigid. Unlike System 1 persons, they tend not to be highly authoritarian and to reject the

prevailing rules, norms, and social order, and to advocate change. Often, movement into System 2 conceptualizing occurs during the latter high school and college age years. Behaviorally, persons may have either an ''approach'' or ''avoidance'' reaction: They may suddenly become campus left-wing activists or, alternately, simply ''drop out'' from the society which has disappointed them. In either case, it is likely to be an indiscriminate ''throw the baby out with the bathwater'' reaction. If asked what they believe should replace the existing social order, they often will advocate some kind of anarchy - such as a simplistic belief of ''let everyone do their own thing''.

For most persons who enter the System 2 stage, it is a reactionary, transitory one - perhaps a few months to several years in duration. As they gain further experience and become more abstract, they move on to a System 3 orientation. Although as many as 10% of the teen age population may be in this stage at any given time, only several percent of adults plateau at this level. Those that do provide a source for the leadership of radical left wing organizations - groups that have high sounding causes but inhumane means of accomplishing them, such as terrorism.

System 3 Functioning: The World is People

The System 2 breaking away from the norm, and learning about how one is distinctly oneself, provides the basis for eventually empathically understanding and accepting differences - from both oneself and the norm - in others (Hunt, 1966). With development of this more abstract realization about others, the individual moves into System 3 conceptualizing. As an overview, for System 3 functioning persons the world is people. Instead of seeing differences in values, religion, race, lifestyles, beliefs, etc. as deviant or ''less than'', as do more concrete functioning persons, System 3 individuals tend to value these differences as enriching their personal lives and the human condition. With this increase in empathy comes a shift to Postconventional moral reasoning.

In marked contrast to System 1 individuals, System 3 functioning persons tend to demonstrate a low need for structure and order, and for simplicity and consistency, and often will express a preference for complexity and change. They tend to have a high tolerance for ambiguity, low absolutism, low ethnocentrism, and an openness of beliefs - in fact, they expect their beliefs to change with increased experience. System 3 persons tend to be moderately authoritarian, but do not hold authority figures in awe, and expect to be questioned when they are in positions of authority. Rules, regulations, and procedures are accepted as useful, but also are seen as needing review and, sometimes, modification as things change to ensure that they remain functional. They tend to have both a high need for people and for helping others. They thus tend to be ''joiners'' and are

empathically concerned with the human condition and factors that affect the quality of life.

In the United States, approximately 25% of the adult population operates from a System 3 orientation; but again, their is a systematic age relationship. Only 10% to 15% of those persons in their late 60's and older appear to be operating from a true System 3 orientation. Among those in their mid 20's to late 40's, approximately one-third appear to be functioning at a System 3 level. Again, those in their 50's and early to middle 60's represent the average. Based on limited research, this same pattern appears to characterize other industrialized countries.

System 4 Functioning: Autonomous, Creative Behavior; Conceptual Maturity

The major developmental task at the fourth conceptual level is the integration of standards which apply to both self and others. This integration enables the individual to understand both self and others as occupying different positions on the same transcendent dimension, rather than seeing self and others simply as being on different standards. In accomplishing this integrating task, the individual develops greater autonomy in thought and action (Hunt, 1966).

To an even greater extent than System 3 thinkers, System 4 conceptualizers rely on Postconventional moral reasoning, have a low need for structure and order and simplicity and consistency, are relativistic rather than absolutist, open minded, creative, flexible, and have a high tolerance for ambiguity. Like System 3 persons, System 4 individuals are people-oriented, but are not highly people dependent - they thus tend not to be joiners; and will be very open and direct in expressing their views, even when they may be unpopular. Although others may have a high perceived self-worth, it seems to be universal among System 4 persons - a precondition for being able to function at the System 4 level.

In terms of their empirically identified characteristics, System 4 individuals appear to be the same persons which, through very different research approaches and models, Maslow identified as true self actualizers, and Carl Rogers as fully functioning persons. All three approaches have identified approximately 10% of the adult population as falling into this group (Hendrick, 1981).

Characteristics Unrelated to Conceptual Systems

It should be noted that several important characteristics that might seem highly related to cognitive complexity and conceptual stage are not. First, when education level is held constant, only a weak correlation is found between abstractness of functioning and general intelligence (Harvey, et. al, 1961). Some of the most brilliant persons from all walks of life appear to have been, and are System 1

functioning individuals. Secondly, conceptual functioning does not appear related to generosity, friendliness, or numerous other valued personality characteristics.

Other Characteristics Related to Abstractness and Conceptual Systems

More cognitively complex functioning has been found to be related to (a) completeness and effectiveness of cue utilization, (b) readiness and ability of persons to relinquish previous assumptions or approaches and change their set in order to complete tasks, (c) use of more novel, yet appropriate responses to problems, and (d) value differences. With respect to values, System 1 persons score higher than more abstract functioning individuals on Scott's Scale of Values for self-control, honesty, kindness, loyalty, religiousness, and the desire for power and influence; System 2 persons value self-control, honesty, kindness, loyalty and religiousness less than all others, and creativity and independence somewhat higher than System 1 persons; System 3 individuals score relatively low on their valuing of self-control and independence, and as high as System 1 persons on kindness, and intermediate on the other values; System 4 conceptualizers value creativity and independence highly, give low value to self-control and religiousness, and are intermediate on the other four dimensions. (Davis, 1966).

Contributions to Our Understanding of Cognitive Complexity and Behavior by the Author

Cogntive Complexity Level and Childrearing Patterns

Harvey, et al. (1961) proposed that reaching a plateau at a particular stage of conceptual functioning is related to exposure to a particular dominant trainer pattern during one's childhood. The essential characteristics of the four trainer patterns identified are as follows.

System 1 Trainer Pattern. Trainers of System 1 adults were hypothesized to have been authoritarian, absolutist, ethnocentric, and closed minded; and to have relied on external sources in their moral reasoning. By the trainer's behavior, conformity rather than creativity of thought and action was emphasized, and the child was given little opportunity to explore values and power relationships.

System 2 Trainer Pattern. System 2 adults' trainers were hypothesized to have characteristics similar to those of System 1 trainers, but also to have been arbitrary and inconsistent. Consequently, the child learned not to trust authority figures or the institutions of social control that they represent.

System 2 Trainer Pattern. System 3 adults were hypothesized to have had trainers who were permissive, overprotective, indulgent, and somewhat socially dependent on the trainee. This enabled the child to take advantage of the depen-

dency relationship to develop skill at manipulating others and, through this, to avoid facing the world alone. The permissive atmosphere allowed the child greater freedom than the System 1 and 2 trainer patterns to explore ideas, values, and relationships.

System 4 Trainer Pattern. System 4 adults were hypothesized to have had trainers who themselves functioned in a highly abstract manner. They tended to relate to the child as an older, experienced adult to a younger, developing adult. The child's behavior was shaped primarily by positive reinforcement, including being rewarded for exploring and trying the different rather than for overt responses matched to narrowly prescribed standards of the trainer. The child was intrinsically valued by the trainer as a person in his or her own right.

To test the above hypothesized relationships, I had 198 practicing managers and engineers, enrolled in nine sections of my graduate organizational behavior classes between 1976 and 1979, write a one page essay describing their childrearing. As part of their essay, these adults were specifically asked to (a) state the nature of their relationship with each parent, or surrogate parent, including the extent to which each parant was authoritarian or permissive, and (b) Indicate how each parant responded when they deviated from parental rules. 156, or 79% of the responses fell clearly into one of four trainer patterns, highly similar to those hypothesized by Harvey, et al.(1961). The others could not be classified into a distinct pattern. All 198 participants were administered Harvey's This I Believe Test (TIB), a measure of both cognitive complexity and conceptual systems (See Harvey, et. al 1961). For the 79% that could be categorized, the correlation between trainer pattern and Conceptual system was .62 ($p < .001$). In general, the conceptual system level of the individuals matched the hypothesized corresponding trainer pattern, but with one exception: The System 4 adults (21 students) were fairly evenly split between having had either the System 3 or System 4 trainer pattern. Most frequently, those persons who had experienced the System 3 trainer pattern reported it for only one of the parents, usually the mother, with the father's role being either largely absent or less influential, and/or that of disciplinarian.

Cognitive Complexity and Traumatic Event

During the 1976-1995 period, I interviewed over 50 persons who experienced the System 1 trainer pattern while growing up, yet had made the transition to System 3 or 4 functioning. The one common characteristic that these persons seem to possess, and to which they attribute their breaking away from the System 1 mold, is having undergone a traumatic event in their adult lives (e.g., near death, death of a loved one, divorce, combat in Viet Nam) which upset their lives and caused them to seriously question their views of reality.

While it appears traumatic events can lead to development of greater abstractness, it often is not the case. Harvey (1966) and Hunt (1966) have emphasized that exposure to diversity can be superoptimal as well as suboptimal, and thus not facilitate conceptual growth.

Cognitive Complexity and Creativity

In 1968, during a required undergraduate introductory psychology class at The U. S. Air Force Academy, over 600 students were asked to write down as many uses as they could think of for their uniform shoulder boards within a five minute period. All students also were administered the AOS measure of cognitive complexity. The cognitive complexity scores then were correlated with both number of uses and instructor ratings, including my own, of originality of the uses. For both number of uses and originality of uses, the cognitively complex students scored significantly higher ($p < .001$) than the more cognitively concrete students. Similar, but less striking results were found for uses of both a pencil and paper clip.

In a related study, the students were asked to write down how they would take their roommate's girl friend out on a date and have him appreciate it. The replies were rated for creativity by two instructors, with a third instructor rater being used to decide the issue when ever there was a disagreement between the first two. The abstract functioning students scored significantly higher on creativity than did the cognitively concrete group ($p < .001$). Using the students' Harvey TIB measures of conceptual system, we found no significant difference between System 3 and System 4 students' replies. The results of these studies are consistent with the cognitive complexity and conceptual systems literature, and lend construct validity to the model.

Cognitive Complexity and Leadership Behavior and Influence

117 male upper class undergraduate students, enrolled in eight sections of an advanced leadership class, were administered the Abstract Orientation Scale (AOS), a measure of cognitive complexity that has shown good correlation with Harvey's TIB and various measures of related dimensions (see Hendrick, 1990 for a brief summary of AOS validation studies). During the course, the students participated in group discussions of case studies and reading materials and took part in various classroom exercises involving dimensions of leadership behavior. These discussions and exercises provided opportunity for each class section member to become aware of each other member, the resources he brought to the class section, and his method and pattern of participation. At the end of the course, each student ranked all of the students in his section, including himself, in terms of the degree of influence exercised in the classroom. These rankings were

summed for each student to determine his composite score. The product moment correlation between composite score and AOS score was .29 ($p < .01$), suggesting that the more cognitively complex students tended to have somewhat greater influence on the group. (Hendrick, 1990)

Observations by myself and the other instructor of the cognitively concrete and cognitively abstract students' behaviors during the class exercises were generally consistent with previous findings for System 1 and Systems 3 & 4 functioning persons, cited earlier. Cognitively concrete persons were more authoritarian, less open to opinions of others, more absolutist in their views, and took longer to change their opinions in the light of new information. In contrast, the more abstract functioning students were more truly participative and empathic, open minded, relativistic in their views, and more flexible in their opinions.

More recently, I have replicated the above study with 53 practicing managers and engineers in three of my graduate organizational behavior courses, and obtained similar results.

Cogntive Complexity and Interpersonal Perception

Fundamental to the interpersonal influence or leadership process appears to be the ability to perceive the behavioral cues of others (Harvey, 1966). Harvey (1966) has summarized a number of studies by himself and others demonstrating that abstract persons have a greater sensitivity to minimal cues and a greater ability to use them appropriately and completely. In order to determine if this ability also applies to interpersonal perception, I had 117 senior and junior male undergraduate students view the film, Twelve Angry Men, which frequently has been used in interpersonal perception research. The first 38 minutes of the film depicts the deliberations of the jury at the end of a murder trial. The film is rich in its portrayal of group dynamics phenomena. Issues of leadership, conformity, and deviation are highly visible in the emerging patterns of interpersonal relationships of the jurors. Each juror exemplifies a distinct personality and his arguments and nuances of behavior easily suggest a degree of attitudinal and behavioral flexibility. The initial vote of the jury is 11 to 1 ''guilty''. The film was stopped at the point where the jurors are about to take a second vote. The students were informed that during the remainder of the film, the jurors would change their vote, one by one, resulting in a final vote of 12 to 0 for not guilty. Each class member then was handed a form, depicting the jury seating arrangement, and asked to number the jurors in the order in which they would change their votes to ''not guilty''. Each student's ranking then was compared with the actual order in which the jurors switched their vote, and a composite error score was computed. These error scores were correlated with their scores on the AOS measure of cognitive complexity. The resulting correlation was .44 ($p < .001$), suggesting

that the cognitively complex students indeed did make better use of the available cues. (Hendrick, 1990).

As part of the leadership influence study, cited earlier, the students' own rankings of their effectiveness, as compared with that of the other class members, were compared with the composite group rankings and an error score for each student was determined. These error scores were correlated with the students' respective AOS scores. The resulting r was .39 ($p < .001$), suggesting that the more abstract functioning students were somewhat more accurate in their self perceptions, as well as in their perceptions of their classmates. (Hendrick, 1990)

Cognitive Complexity and Group Task Performance

One of the most dramatic differences between abstract and concrete functioning persons that I have observed has been in two studies of group task behavior (Hendrick, 1979). In these two studies, the cognitive complexity levels of 100 cadets at the U. S. Air Force Academy and 100 experienced managers enrolled in a graduate management program at a large private university were assessed using the AOS. The five highest and five lowest scorers in each of 20 class sessions were assigned to abstract and concrete problem-solving groups, respectively. The group problem solving task used was the Broken Squares exercise, described by Pfeiffer and Jones (1969) in their handbook. The exercise consists of five identically sized cardboard squares, consisting of three sections, thus forming a puzzle, with no two puzzles being alike. At the beginning of the task, each participant is given an envelope containing three puzzle pieces, each from a different square. The participants are instructed to complete all five squares as quickly as possible. They further are instructed that they are not to talk or gesture, can only pass pieces to the person to their right or left around the table, and must wait for pieces to be passed to them.The 20 concrete groups took almost twice as long as the 20 abstract groups to complete the task ($p < .001$). Compared to concrete groups, abstract group members interacted at a faster pace and demonstrated better cue utilization ($p < .001$). No differences were found between the undergraduate and graduate groups.

In addition to the systematic observations of group problem solving behavior, several other behavioral characteristics on which their were striking differences between the concrete and abstract groups were informally noted. These included (a) a tendency of abstract groups to demonstrate greater flexibility of set by a willingness to break up completed squares to try alternate combinations; (b) a tendency of abstract groups to test the rules to determine their real limits, whereas concrete groups did not; and (c) a tendency of concrete group members to focus primarily on their own individual task, whereas abstract team members tended also to focus on the work of other team members.

Cognitive Complexity and Stratified Systems Theory

Stratified systems theory holds that hierarchical differentiation of jobs in organizations differ systematically in their cognitive complexity requirements, and that managers perform most effectively and are happiest when their own cognitive complexity level matches that of their position (Stamp, 1981). Based on this hypothesis, the cognitive complexity levels of 22 hotel General and Resident Managers for a large hotel chain were assessed using both the AOS and a composite of four scales of the Guilford-Zimmerman Temperament Survey. All 22 managers were assessed by their superiors as being successful in their present positions. The 22 managers each were evaluated by the Hotel Division's Vice President for Operations Support in terms of his potential for promotion to Area Manager - the next hierarchical level and one in which the manager exercises supervision indirectly over a group of hotels and their employees, thus making it more cognitively complex. Of the nine managers scoring as cognitively complex, seven were evaluated as having high potential for promotion to Area Manager. Of the thirteen managers scoring as cognitively concrete, only four were evaluated as having high potential for promotion ($\phi = .57, p < .01$). These results appear to offer partial support for the stratified systems hypothesis.

Cognitive Complexity and Interpersonal Communication

Implicit in the cognitive complexity literature is a message concerning communicating with persons of differing levels of complexity which is consistent with my 30 years of experience as both an organizational consultant and teacher of practicing managers: Namely, express your message in terms of the other person's conceptual reality - to use a trite but true expression, from where he or she is "coming from". With concrete functioning persons, it is important to express ideas in specific, concrete terms. For example, if trying to persuade a concrete functioning manager to approve some organizational change intervention, it is important to describe the intervention in a clear, step-by-step fashion and, especially, the rationale for the intervention in terms of how it will improve the manager's "bottom line". In contrast, more abstract functioning managers are likely to respond positively to a description of the approach in terms of its underlying rationale and its less tangible benefits, such as improving employee job satisfaction and commitment, reducing stress, and being "the right thing to do" from a human consideration point of view.

Use of the Cognitive Complexity Dimension in Organizational Design

Organizational structures generally are acknowledged to have three major dimensions: Complexity, formalization, and centralization (Bedeian and Zammuto,

1991; Robbins, 1983; Stevenson, 1993). Like cognitive complexity, organizational complexity also has the two major components of differentiation and integration. Organizational differentiation refers to (a) the number of hierarchical levels or vertical differentiation, (b) the degree of departmentalization and specialization, or horizontal differentiation, and (c) the geographical dispersion of organizational units and employees, or geographical differentiation. Increasing any of these increases the organization's complexity. Organizational integration refers to the mechanisms that are used to coordinate and control the differentiated elements. These include such things as standard operating procedures, committees, task teams, information systems, integrating offices and vertical hierarchy (e.g., one boss supervises two or more subordinate units, thus serving as the integrator). Formalization refers to the extent to which operations rely on formalized procedures, standardized communications and detailed job descriptions, rather on employee expertise and decision-making. Centralization refers to the extent to which decisions are made by managers, higher up in the organization, versus being delegated to lower employee levels.

Among other factors, the optimal degrees of complexity, formalization and centralization to incorporate into an organization's design depend on the characteristics of the work force. In particular, the (a) degree of education and training or professionalism, and (b) the psycho-social characteristics of the employees (Robbins, 1983). With respect to the psycho-social characteristics, I have found one of the most useful integrating factors to consider is that of cognitive complexity.

Given the characteristics, already described, it is not surprising that, in my 30 years of consulting, I have found concrete functioning managers and employees alike to prefer the clear, unambiguous structure and formalization of bureaucratic organizational designs. In contrast, abstract functioning managers and employees usually prefer low formalization, decentralized decision-making; and are very comfortable in more complex or less structured, more ambiguous organizations (e.g., professionalized, matrix, and continuously changing or free-form designs).

I also have found more abstract managers to be comfortable with the use of employee participation and decentralized decision making, whereas concrete functioning managers often are resistant to these practices, and prefer to use a more authoritarian and controlling management style.

Conclusion

From the above historical review of cognitive complexity and its relation to moral reasoning, conceptual systems, and behavior, and of my research contributions to our knowledge of cognitive complexity and performance, it should be apparent that

the cognitive complexity dimension can be of considerable benefit to engineering psychologists and ergonomists. From my experience, I believe that many of the inconsistencies in human performance, often found between persons in the same or similar situations, can be explained by a knowledge of the complexity levels of the individuals involved. Similarly, knowledge of the complexity levels of persons in a given environment can better enable us to structure that work situation to better enhance worker performance and satisfaction.

The cognitive complexity literature also suggests that knowing the complexity level of individuals may better enable us to design both management information systems and training programs for them. For example, more structured, step-by-step linear presentation of data and procedures is likely to better serve cognitively concrete persons, with their greater need for structure, order and formalization. In contrast, systems which focus more on communicating or teaching general principles and cognitive maps are likely to be more intrinsically interesting and satisfying to cognitively complex persons. These are but two hypotheses of potentially useful applications of cognitive complexity that remain to be validated.

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The Effect of Individual Differences on Anxiety and Team Performance[1]

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ABSTRACT

Because stressors impact individuals and teams in a variety of occupations and environments, research regarding occupational stress has become increasingly critical. A concurrent trend is the increasing role of teams in a wide variety of environments. Because it is often necessary for teams to perform under conditions characterized by stress, there is a clear need for investigations of the factors which might impact the performance and subjective distress of teams under stress. Although some past research has considered the impact of individual differences on team performance under stress, the literature on individual differences and stress has primarily been concerned with individual responses to stressors. The current study investigated the relationships among individual difference characteristics, team performance, individual distress, and coping in teams performing under conditions of stress related to the task being performed and under conditions where the stress was unrelated to the task being performed. Specific hypotheses were tested with regard to the impact of self-control and the manipulation of perceived control with regard to individual anxiety, team performance, and team member coping. Mixed support was obtained for these hypotheses. Possible explanations are considered for these findings and directions for further research are discussed.

Stress is one of the most critical and enigmatic areas of psychological research. Because stressors impact individuals and teams in a variety of occupations and environments (e.g., fire fighting, the military, medical occupations) research regarding occupational stress has become increasingly critical. In fact, occupational stress has been referred to as the threat to work (Cox, 1978). Thus, it is apparent that stress is worthy of the attention of researchers interested in gaining an understanding of the health, psychological, and performance effects of stress.

A concurrent trend is the increasing role of teams in a wide variety of environments. Although it has been noted that the quantity of team research conducted regarding team processes and performance has not kept pace with the frequent use

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of teams, it appears that this situation is beginning to change (Salas, Dickinson, Converse, & Tannenbaum, 1992). Because it is often necessary for teams to perform under conditions characterized by stress, there is a clear need for investigations of the factors which might impact the performance and subjective distress of teams under stress.

Because a team consists of at least two or more individuals working toward a common goal in an interdependent fashion (Morgan, Glickman, Woodard, Blaiwes, & Salas, 1986), team performance would appear to be particularly susceptible to the effects of stress. That is, the requirement for teams to maintain acceptable performance by interacting effectively with team members under stress in addition to the need for individuals to maintain their own performance, places an additional level of demand or "resource strain" on a team and its members. Thus, there is a need for research regarding the relationship of stress to team performance, and the investigation of factors which might impact a team's performance and the subjective distress of its members under stress.

The current effort addresses this need by selecting a well accepted, existing model of stress deemed to be relevant for adaptation and application to the study of team stress. The coping construct and the role of self-control and social support, in this regard, are described in light of the model and a rationale is presented to explain the stress manipulation employed in the current study. This rationale is built around a discussion of past research conducted on the perceived control construct. Finally, research hypotheses are delineated, and the method of study is detailed.

Background

Stress in Teams

Relatively little systematic inquiry is available regarding stress in groups and teams (Driskell & Salas, 1991). Morgan and Bowers (1995) note that this lack of attention is becoming increasingly critical because many jobs in both the military and civilian sectors require groups of individuals to work together effectively in teams. Often these teams must make quick and effective team decisions in complex, stressful occupational environments. Similarly, Driskell and Salas (1991) note that the lack of knowledge regarding teams under stress is surprising for several reasons: (a) because the complexity and breadth of many present-day systems often require the combined efforts of a group, (b) in order to understand outcomes associated with these tasks, an understanding of group processes must be gained, and (c) because group interaction patterns will be impacted by stress and other environmental factors.

Because the nature of team tasks, such as tactical decision making (Cannon-Bowers, Salas, & Grossman, 1991), aviation (Weitz, 1970), and fire fighting (Fullerton, McCarroll, Ursano, & Wright, 1992), is inherently stressful, it is apparent that these team situations should be investigated further. The impact of stress in a variety of team environments and the criticality often associated with related outcomes make the investigation of stress in teams an important undertaking.

Alluisi and his colleagues investigated the impact of various stressors (e.g., continuous work, illness, sleep loss) on team performance. Within the investigation of Morgan, Coates, Brown, and Alluisi (1974), two five-man crews performed both team and individual synthetic tasks included in a Multiple Task Performance Battery (Morgan & Alluisi, 1972). In their investigation of the effects of continuous work and sleep loss, Morgan and his colleagues found that team performance recovery was related to the length of the continuous work period. That is, a 44 hour period of continuous work produced an average decrement of 22%, while a 36 hour period was associated with decrements between 14 and 18%.

Morgan and his colleagues' study of team performance was complemented by an investigation of the impact of individual differences on team and individual performance under conditions of extended operations. Morgan, Winne, and Dugan (1980) reexamined and reanalyzed data previously obtained in Morgan et al. (1974) in order to investigate the range and consistency of individual differences of members in the two five-man crews. Results indicated that individual differences in performance ranged from 0-40% after 32 hours of continuous work. Their general findings indicated that individuals performed relatively consistently throughout several exposures to such stress. These authors noted the proposition of Wilkinson (1974) that individual differences in response to environmental stimuli be investigated in order to gain an understanding of stressor effects in team performance.

Although some past research has considered the impact of individual differences on team performance under stress, the literature on individual differences and stress has primarily been concerned with the individual (Jex & Beehr, 1991). Studies such as that conducted by Morgan and his colleagues are relatively rare.

Recently, however, interest has again been sparked in the role of individual differences in relation to team performance under stress. The work of Weaver and her colleagues (Weaver, Morgan, Adkins-Holmes, & Hall, 1992; Bowers, Weaver, & Morgan, 1996) identified a number of variables which might serve to moderate the effects of stress on team performance. These authors argue that a clear understanding of stress and its effects can be gained only by identifying and investigating factors which impact the relationship between stressors and outcomes. An understanding of these so called moderator variables might enable researchers to better predict the effects of stress, conduct research which would

allow an unobscured view of stress effects, and design effective interventions for the control of stress (also see Jex & Beehr, 1991).

The literature regarding stress at the individual and team levels have often differed in the outcome variables studied. That is, whereas the majority of the individual stress literature often considers the ''feelings'' or subjective reactions of people confronted with stressful circumstances (e.g., life events research), the team stress literature reflects a preoccupation with gaining an understanding of stressors in relation to performance outcomes. Perhaps this is to be expected since ''team stress'' has been investigated less, and it began as an outgrowth of a need to understand the workings of teams in operational settings. However, the current study attempts to merge these two approaches by simultaneously considering subjective and performance outcomes. Furthermore, an understanding of the relationship between these two outcomes and individual differences, within the members of the team, might provide valuable insight into the stress phenomenon. Thus, a primary purpose of this study was to investigate the effects of ambient and performance contingent stress, in line with the suggestion of Driskell and Salas (1991), with attention to individual differences and their impact on member distress and team performance.

Stress and Coping

Lazarus and Folkman (1984) define stress as ''a particular relationship between the person and the environment that is appraised by the person as taxing or exceeding his or her resources and endangering his or her well-being'' (Lazarus & Folkman, 1984, p. 19). The ''resources'' component of the definition refers to what one draws upon in order to cope.

In addition to the inclusion of components of stress, appraisal, and coping variables, person and environment antecedents of stress and coping, short- and long-term adaptational outcomes are also included in Lazarus and Folkman's model of stress and coping. Person variables are defined as characteristics of persons which influence their situational appraisal. The authors argue that person variables influence appraisal ''by (1) determining what is salient for well-being in a given encounter; (2) shaping the person's understanding of the event, and in consequence his or her emotions and coping efforts; and (3) providing the basis for evaluating outcomes'' (Lazarus & Folkman, 1984, p. 55). Two such person variables are commitments and beliefs. Lazarus and Folkman note that person and situational variables are highly interdependent. That is, although many situations might appear to be universally stressful, individual variations are great. Therefore, it is important to consider situational and person variables simultaneously.

The next component of the stress model is appraisal. Lazarus and Folkman (1984) note that although certain situations produce stress in a large number of persons, individual and group differences exist in the extent and type of reactions. The authors define appraisal as "the process of categorizing an encounter, and its various facets, with respect to its significance for well-being" (Lazarus & Folkman, 1984, p. 31). The process is argued to be evaluative, focused on significance, and continuously occurring. In addition, there are two types of appraisal; primary and secondary. Primary appraisal focuses on the implications of a stressor while secondary appraisal focuses on what can be done about the situation. Finally, Lazarus and Folkman (1984) hypothesize that these appraisals are not always conscious and can be determined by factors below an individual's awareness.

Coping is defined as "cognitive and behavioral efforts to manage specific external and/or internal demands that are appraised as taxing or exceeding the resources of the person" (Lazarus & Folkman, 1984). Lazarus and Folkman (1984) also argue that coping serves two functions: (1) problem-focused coping manages or alters the problem within the environment which is causing distress, (2) emotion-focused coping regulates emotional responses to problems. As a method for investigating the coping process, Lazarus and his colleagues developed an assessment instrument called the Ways of Coping Scale (Folkman & Lazarus, 1980), which assesses both problem and emotion focused coping. Although most stressors might trigger both types of coping, emotion focused coping is most salient when people feel that nothing can be done to reduce or obviate the stress, while problem focused coping becomes more salient when persons feel that something can be done (Carver, Scheir, & Weintraub, 1989).

Lazarus and Folkman (1984) also describe the role that self-control, or self-regulating cognitive skills, plays as a resource within the coping process. They note that "the capacity for self-control" (Rosenbaum, 1980b) is an important predictor of problem solving ability in the context of coping. Thus, self-control is considered within the context of individual coping because of its potential to contribute resources in relation to problem and emotion focused coping.

Self-control or "learned resourcefulness" is defined as "an acquired repertoire of behavioral and cognitive skills with which the person is able to regulate internal events such as emotions and cognitions that might otherwise interfere with the smooth execution of a target behavior" (Rosenbaum, 1983, p. 55). Rosenbaum (1980a) argues that persons who use self-control methods to manage pain, thoughts, and emotions are able to reduce the negative effects of maladaptive behaviors. Therefore, the use of self-control techniques might prove particularly effective as a method for coping with stressful situations.

Past research has supported the utility of the self-control or "learned resourcefulness" construct as discussed by Rosenbaum, for predicting effective performance

in aversive circumstances. For example, Gal-Or, Tenenbaum, Furst, and Shertzer (1985) investigated the relationship of self-control and trait anxiety to performance in a sample of 44 trainee parachutists. The results of the study indicated that best performance was exhibited by parachutists with high self-control regardless of their trait anxiety. Another study, conducted by Rosenbaum and Rolnick (1983) investigated the relationship between seasickness and the use of self-control behaviors in eighty-nine sailors of the Israeli Navy. The results of this study indicate that high self-control subjects who became seasick exhibited fewer performance decrements than did those subjects who were low in self-control. Interestingly, there was no difference between low and high self-control subjects in their susceptibility to become seasick, but only a difference in their capabilities to perform when seasickness was upon them. Thus, although self-control did not prevent the onset of sickness, persons high in self-control were better able to cope with their illness and maintain better performance under the stressor of being ill. Therefore, these studies provide interesting data with which to speculate about the potential effects of self-control on performance under stress. Investigations of self-control are also interesting in order to provide support for (or against) the value of stress inoculation training (SIT) for military team members as a method for coping and maintaining effective performance under stress.

Team Coping

To date, coping has not been treated at the team level. However, similar constructs have been investigated such as cohesion and social support. For the purpose of the current study, only social support will be considered. Although their reference was to individuals, Lazarus and Folkman (1984) have discussed the role that social support can play in contributing resources within the coping process. Social support has been defined as:

> attachments among individuals or between individuals and groups that serve to improve adaptive competence in dealing with short-term crises and life transitions as well as long-term challenges, stresses, and privations through (a) promoting emotional mastery, (b) offering guidance regarding the field of relevant forces involved in expectable problems and methods of dealing with them, and (c) providing feedback about an individual's behavior that validates his conception of his own identity and fosters improved performance based on adequate self-evaluation (Caplan & Killilea, 1976, p. 41).

Social support is important in the context of coping as it ''provides vital resources from which the individual can and must draw upon to survive and flourish'' (Lazarus & Folkman, 1984, p. 243). Carver et al. (1989) also note that seeking out social support acts as a coping response. People seek out social

support for one of two reasons: social support for instrumental reasons and social support for emotional reasons. Instrumental reasons can be seeking advice, assistance, or information while emotional reasons are related to obtaining moral support, sympathy, or understanding (Carver et al., 1989). The former is a type of problem focused coping while the latter is a form of emotion focused coping. Because social support, by definition, requires interactions with others, the construct is particularly important for the investigation of team performance.

Ironically, relatively little attention has been paid to the role of social support in research regarding teams under stress. One exception to this surprising trend is a study conducted by Fullerton et al., (1992). These authors investigated the psychological responses of fire-fighting teams. In particular, the authors were interested in factors serving a moderating function of the extreme stress involved in dealing with the traumatically injured (e.g., mass-casualty air disasters). Their results indicated that all of the fire-fighters involved in the study noted the importance of social support from fellow workers. This was noted to be the case particularly in regard to decision making, staying task focused, providing reassurance, and maintaining a sense of humor (Fullerton et al., 1992).

For the purpose of consideration within the realm of team research, it is suggested that the coping portion of the Lazarus model be considered in terms of two separate resource components represented by self-control and social support. The first coping component represents the resource of self-control which originates from within individual team members. Because a key component of research regarding teams rests in the interdependent and interactive activity of its members, the coping component is expanded to describe coping which is facilitated or generated from the interactions of the team members. An example of this type of coping is social support. Consistent with the paradigm established by Lazarus and Folkman (1984), each of these components is then further divided into two dimensions. These dimensions for both the individual and team resources can be task (problem-focused) or non-task (emotion-focused) related. As noted above, Lazarus and Folkman (1984) describe two sub-types of coping; namely, emotion and problem focused coping. Problem focused coping is directed at managing the problem itself, while emotion focused coping is directed at management of the emotional response to the problem. One goal of the current study was to test the extent to which social support and self-control are differentially related to coping behaviors assessed by the Ways of Coping questionnaire, performance, and state anxiety.

Perceived Control of Stress

Because of the belief that control perceptions are implicated in coping and stress, the perceived control construct has provided a compelling topic of research

for psychologists. In fact, as early as 1966, it was argued by Lazarus that the less control individuals possess in threatening situations, the more likely they are to feel helpless and distressed by situations (Lazarus, 1966). Weaver et al. (1992) argued in their review that perceived control might be the common mechanism to explain the effectiveness of variables which moderate outcomes associated with stress.

Perceived control has been defined as ''the belief that one has at one's disposal a response that can influence the aversiveness of an event'' (Thompson, 1981, p. 89). Thompson (1981) notes that this definition is advantageous in that it is general enough to include all types of control while simultaneously recognizing that control does not have to be exercised in order to be effective. Furthermore, the definition implies that control does not really even have to exist in order to be effective as long as it is perceived. However, the effects of perceived control are not as well understood as this definition would appear to imply. In fact, reviews of the effects of perceived control have indicated that the belief in an event's controllability does not always lead to reduced stress while beliefs in the uncontrollableness of a stress situation do not always lead to increased stress (Folkman, 1984; Thompson, 1981; Averill, 1973). Thus, there is a need for further research regarding the circumstances under which perceived control is associated with positive performance and subjective outcomes.

The effects of perceived control have been investigated in relation to such diverse stimuli as noise (Corah & Boffa, 1970; Glass & Singer, 1972; Cohen & Weinstein, 1981), heat (Bell & Greene, 1982), and air pollution (Evans & Jacobs, 1982). One of the most often used manipulations in investigations of perceived control is threat of shock (Haggard, 1943; Averill, O'Brien, & DeWitt, 1977; Ball & Vogler, 1971; Staub, Tursky, & Schwartz, 1971). In addition, the effects of perceived control have been investigated in the organizational literature in relation to such factors as job satisfaction, commitment, and performance (see Spector, 1986 for a meta-analytic review of this topic).

Behavioral control is most relevant for the manipulation of stress within this investigation. That is, the current investigation exposes persons to stress in two conditions: (a) one in which the stressor is ambiently derived and, thus, uncontrollable, and (b) the other in which the stressor is task contingent and avoidable by maintaining effective task performance. Results regarding the effect of behavioral control on arousal during stressor impact are far from clear. While some studies have found decreased arousal for subjects receiving shock (Geer, Davison, & Gatchel, 1970), others have found no effect of behavioral control on arousal during receipt of loud noise (Glass, Reim, & Singer, 1971). Still others have found increased arousal at impact of loud noise (Gatchel & Proctor, 1976).

Similarly, studies of the effects of behavioral control on self-reported distress

at stressor impact yield mixed results. For example, several studies (Averill & Rosenn, 1972; Staub et al., 1971, experiment 1; Sherrod, Hage, Halpern, & Moore, 1977) have found that behavioral control is not associated with a lesser tendency to report subjective distress under shock or loud noise, while others (Staub et al., 1971, experiment 2; Glass et al., 1971) have found that behavioral control does have an impact on subjective distress under shock and noise stress conditions.

Fortunately, the equivocality of the perceived control research has been addressed by Driskell, Mullen, Johnson, Hughes, and Batchelor (1991). These researchers performed a meta-analysis of studies which assessed the effects of uncontrollable shock on self-reported distress or performance accuracy. The authors note that only shock studies were used due to the common nature of this manipulation in the control literature. In addition to their investigation of the effects of perceived control, the authors also sought to account for the effects of the meaning of the delivery of shock. That is, the authors note that in some studies shocks are actually delivered whereas other studies only threaten to deliver shocks. Thus, Driskell et al. (1991) sought to determine the effects of this manipulation as well.

Driskell et al. (1991) summarize their results in the following manner. Their hypothesis that having control would be associated with less stress was supported only when shocks were not actually delivered. Thus, in situations in which shock was threatened but not delivered, less stress was reported when persons had control. In their "guidelines for manipulating uncontrollableness" Driskell et al. (1991) state that "these analyses show that uncontrollable shock can be used as a powerful laboratory stressor to elicit subjective stress and decrements in performance accuracy. Greater effects are shown under conditions of anticipatory stress, when the stress is perceived as imminent, but never occurs" (Driskell et al., 1991, pp. 105-106). This manipulation was used in the current study. That is, subjects were threatened with shock, but they never actually received shocks during task performance. A later section describes the method of past studies which have used threat of shock, in order to establish the logistics of the manipulation and the level of shock which can be used safely.

Rationale of the Current Study

One purpose of the current research was to explore the utility of the Lazarus model for application to research regarding team stress. That is, it is suggested that teams possess, to a greater or lesser extent, resources which contribute to their ability to cope under stress. Consequently, outcomes (e.g., team and individual

performance, and member distress) are impacted by this coping ability. Therefore, the proposed definition of team stress is a direct outgrowth of the Lazarus definition of individual stress, that is, team stress is a particular relationship between the team and their environment that is appraised by the team members as taxing or exceeding their resources and endangering their well-being. Based upon the theoretical underpinnings of Lazarus' work, the current study sought to investigate the relationship between two types of coping resources, social support and self-control, and subjective and performance outcomes. Although the appraisal component is obviously critical, this preliminary investigation did not attempt to assess this component.

The current study investigated the relationships among individual difference characteristics, team performance, individual distress, and coping in teams performing under conditions of stress related to the task being performed and under conditions where the stress was unrelated to the task being performed. Because the coping variable of primary interest was self-control, and because social support has been demonstrated to have an impact under stress, the current study assessed both. However, the study was designed so as to directly assess the effects of self-control while controlling for the effects of social support. Because relatively few studies have been devoted to the investigation of teams under stress and the factors which influence related outcomes, it was anticipated that this investigation would yield useful information regarding the processes and performance of teams under stress. The following section details the hypotheses tested within this study based upon the reviewed literature above.

It has been noted (Lazarus, 1993) that cognitive methods of coping (e.g., self-control behaviors) are relatively stable, while perceived social support is cumulative and depends on prior interactions. Therefore, these variables were differentially treated in the current investigation. That is, teams were formed by selecting individuals for level of self-control. Social support was assessed from these teams, and the data were analyzed on the basis of the social support ratings. In order to assess the effects of social support, an existing measure for the assessment of perceived social support (Inventory of Socially Supportive Behaviors) was adapted for use in the current study. The effects of each coping variable were investigated in relation to performance and subjective stress outcomes.

Hypotheses

1) Team members high in self-control were expected to report less anxiety than low self-control members.
2) Teams composed of high self-control members were expected to outperform teams composed of low self-control members as assessed by team score, query time, penalty points, and number of items queried.

3) Teams composed of high self-control members were expected to report different coping behaviors as assessed via the Ways of Coping Questionnaire than low self-control member teams.

Preliminary investigations of team stress such as this one, should attempt to ascertain the extent to which teams are differentially affected by stressors that impact individual members more directly (e.g., more environmental types of stressors) relative to stressors that are more relevant to the interactions within the team (e.g., related to the task the team is attempting to perform). It has been suggested that a new class of stressors be considered as relevant for investigation in teams. These teamwork stressors, defined as ''stimuli or conditions that (a) directly impact the team's ability to interact interdependently or (b) alter the team's interactive capacity for obtaining its desired objectives'' (Morgan & Bowers, 1995), are argued to have a direct impact upon the team's interaction and coordination. It might be beneficial to divide this class of stressors further into stressors which originate from an ambient vs. a performance contingent source. Indeed, it has recently been suggested that there is a need for investigations of ambient vs. performance contingent stress on the performance of teams (Driskell & Salas, 1991). Although perceived control has been relatively well investigated in relation to individuals, there is a need for investigations of the effects of perceived control on teams. Furthermore, there is a need for studies of the extent to which teams are differentially impacted by stress originating as a component of the task performed as compared to stress originating from other sources. Such investigations will allow researchers to determine which source of stress might be more deleterious for team performance. In turn, this will provide direction for further research regarding team stress. Hypotheses regarding the stress manipulation and the coping variables discussed above are listed in the following section.

Hypotheses

1) Team performance in the ambient stress condition was expected to be inferior to that of performance in the performance contingent condition, but performance in the performance contingent condition was expected to be significantly worse than the condition in which no stressor was presented.
2) A significant interaction (trial by self-control) was hypothesized such that high self-control teams were expected to perform better in the ambient stress condition than low self-control teams with a smaller difference between low and high self-control team performance in the performance contingent condition.
3) State anxiety in the ambient stress condition was expected to be higher than in the performance contingent condition, but distress in the performance contingent condition was expected to be significantly higher than the baseline condition.

Method

Participants

Sixty-four, University of Central Florida male undergraduate students were solicited to comprise thirty-two, 2-member teams. Subjects were awarded research credit for their participation.

Experimental Design

Independent Variables

Stressor type. Two types of stressor conditions were manipulated in the current study. These conditions were threat of shock contingent upon poor task performance and threat of shock presented as ambient or unrelated to task performance. Both of these conditions were compared to a post-asymptotic baseline session with no shock threat.

As previously noted, subjects were threatened with shock, but they did not actually receive shocks during the experimental periods of task performance. However, consistent with past shock threat research and in order to increase the salience of the threat, subjects received a mild but uncomfortable shock just prior to the two experimental periods. This is an adaptation of the method used in other shock threat research.

A common method of manipulating shock threat is to conduct a session prior to the experimental period to establish ''shock tolerance.'' This procedure has been utilized in a number of studies (Beck, Barlow, Sakheim, & Abrahamson, 1987; Beck & Barlow, 1986; Geer et al., 1970; Harris, 1981). The purpose of this procedure is ''to alleviate any ambiguity as to the nature of the shock stimulus'' (Harris, 1981, p. 383). Thus, the salience of the threat manipulation is insured. Another technique has been to include ''dummy trials'' on which performance data are not collected (Averill et al., 1977). Thus, shock-threat investigations which have exposed subjects to shock prior to, but not during the experimental sessions, have taken steps to insure that the threat manipulation is believable.

Researchers have noted that because the threat of shock may not always be believable, it is possible for this manipulation to be ineffective with regard to producing stress (Britt & Blumenthal, 1991). Therefore, it is necessary for researchers to insure the effectiveness of the threat by including a manipulation check or some manner of increasing the salience of the threat. In the current study, the salience of the threat was increased by presenting subjects with a

"sample" shock prior to each experimental session. Overall, only two mild shocks were given to each subject.

The research cited above has used shocks ranging from 1.0 to 10.0 mA for a typical period of 0.5 second. Harris (1981) utilized a 60 Hz constant current source with a shock intensity of 1 mA for a 0.5 sec duration. She notes that this is consistent with that used by other investigators (Furedy & Doob, 1972), and that pilot testing on volunteers indicated that they found this level painful but not so much so that they would refuse to continue.

The current study employed the same level of shock as that used by Harris (1981). This is the lowest amperage reported in prior studies to be effective in its aversiveness. Subjects were informed prior to the beginning of the experiment that an "uncomfortable but harmless shock" would be used and that they could leave without penalty at that or any other time throughout the experiment. The apparatus used to conduct the shock will be described in the method section of this report.

Self-control. Two levels of self-control (low and high) were compared. Teams of low self-control individuals and teams of high self-control individuals were constructed by pairing individuals based on their scores on the Rosenbaum Self-Control Schedule (SCS) (Rosenbaum, 1980b). High self-control teams were created by pairing persons who scored in the upper quartile, and low self-control teams were formed by pairing persons scoring in the bottom quartile.

The method of assessment used for determination of level of self-control is the Self-Control Schedule (SCS) (Rosenbaum, 1980b). This 36-item self-report instrument assesses the extent to which individuals utilize methods of self-control in order to solve behavioral problems. The components of the scale are (a) use of cognitions and self-instructions to cope with emotional and physiological responses, (b) application of problem-solving strategies, (c) ability to delay immediate gratification, and (d) belief in one's ability to self-regulate internal events (Rosenbaum, 1990). Rosenbaum (1990) also notes that past studies have shown that there are relatively large individual differences even in rather homogenous populations. Interestingly, responses on the Self-Control Schedule have been investigated in relation to Lazarus and Folkman's Ways of Coping Scale (1980). Gintner, West, and Zarski (1989) studied responses of eighty graduate students on the scales by comparing coping of high and low self-control students prior to and following a midterm exam. High self-control persons used more problem focused coping during the week of preparation while low self-control persons resorted to more wishful thinking and distancing during preparation and more wishful thinking and self blame during the waiting week. Overall, high self-control persons reported fewer stress symptoms than low self-control persons.The SCS has been demonstrated to possess adequate psychometric properties (Rosen-

baum, 1980b). Test-retest reliability of .86 has been computed over a four week period and internal consistency coefficients have ranged from .78 to .84. A measure of validity has been obtained by way of comparison with the Rotter I-E Scale. It was hypothesized that individuals high in self-control would be internal in their locus of control. A Pearson correlation of -.40 ($p < .01$) was computed between the Self-Control Schedule and the Rotter scale. This coefficient indicated that individuals who reported greater use of self-control methods believed less in the external control of their behavior.

Other indicators of the scale's validity have also been found (Rosenbaum, 1990). As assessed by this instrument, high self-control has been found to be associated with an individual's ability to (a) tolerate clinical and laboratory induced pain, (b) succeed in weight reduction, (c) cope with seasickness, (d) handle helplessness manipulations, and (e) cope with demanding medical treatment regimens (Rosenbaum, 1990).

Dependent Variables

Performance. Four performance measures were obtained from each of three task sessions. These measures are explained in a later section which describes the task.

State anxiety. The measure used to gauge subjective distress was the Spielberger State-Trait Anxiety Inventory (STAI) (state portion) (Spielberger, Gorusch, Lushene, 1970). Subjects were asked to respond to this self-report measure four times during their participation (i.e., when first entering the experimental situation, immediately following baseline task performance, and immediately following each stress condition).

The STAI has been effectively utilized as a measure of state anxiety and has been shown to possess adequate psychometric properties. The instrument is a two-part scale which assesses both state and trait anxiety. Each part contains 20 items that either indicate an absence of anxiety or describe anxiety symptoms. The trait scale requires that individuals indicate on a four-point scale the frequency of times that they experience anxiety symptoms, while the state scale calls for ratings of intensity of anxiety symptoms at a particular time (Spielberger, Vagg, Barker, Donham, & Westberry, 1980).

Test-retest reliabilities of the trait scale have ranged from .73 to .86, while the reliabilities for the state scale have ranged from .16 to .54 (Anastasi, 1976). In addition, Kuder-Richardson reliabilities for both scales have ranged from .83 to .92. Validity has been established via factor analysis. Kendall, Finch, Auerbach, Hooke, and Mikulka, (1976) factor analyzed the scale and distinguished one trait factor and two state factors.

Coping. Coping actions were assessed through self-report using relevant items

from the Ways of Coping Questionnaire (Lazarus & Folkman, 1984). Coping was assessed following each of three task sessions.

Social support. A self-report measure of perceived social support was adapted for this study from an existing measure of social support (Inventory of Socially Supportive Behaviors; Barrera, Sandler, & Ramsay, 1981). This score was obtained three times. Specifically, measures of social support were obtained following each post-asymptotic performance session. The scores on the social support measure were utilized as a covariate in analyses regarding performance and anxiety.

Apparatus

Task

Two networked IBM compatible computers were utilized to present a previously developed team decision making simulation. The task used for this study was the Tactical Naval Decision Making System (TANDEM) (Weaver, Morgan, Hall, & Compton, 1994).

The TANDEM is a networked radar simulation which requires team members to query and integrate information in order to make accurate decisions regarding the type, threat, and intent of incoming targets. Teams receive points based upon the decisions made and consequent actions taken. In other words, teams are required to both label targets based upon type, threat, and intent decisions and engage targets accordingly. For a detailed description see Weaver et al. (1994).

The performance measures obtained were as follows. The first measure was team score. This score is based on the number of points received for correct team decisions minus the number of points lost for an incorrect team decision. In addition, this score is also impacted by the number of penalty points assessed for allowing incoming targets to get "too close." Query time was the second performance measure considered. Query time is the amount of time spent querying target information. The number of information items queried was also measured. This is the total number of items queried. The final performance measure considered was penalty points. This represents the number of points assessed for allowing incoming targets to remain "too close' as demarcated by the known penalty circles. These four measures comprised the performance measures of interest.

Shock Generator

In addition to the materials described above, a capacitor was used to present two "test shocks" to both team members simultaneously. This apparatus gener-

ated 0.5-second shocks at a level of 1mA and 70 volts. As previously described, this is consistent with past research in that these shocks are at the low end of the continuum of those used safely in the past.

Procedure

Pilot-Studies

Before the experimental studies were conducted, 20 pilot teams were tested in order to determine the amount of time necessary to reach asymptotic performance. These studies required subjects to perform eight, 20-minute sessions (a total of 2 hours and 40 minutes) for this purpose. This time period was based upon the knowledge that previous three-person TANDEM studies required a period of 1 $^1/_2$ hours to reach asymptote (Weaver, Bowers, & Morgan, 1994). Results of these pilot studies indicated that there was no change in team performance for sessions four through eight. Thus, asymptote was reached after the first hour of task performance.

In a second pilot-study, self-control levels of potential subjects were assessed by administering Rosenbaum's Self-Control Schedule questionnaires to 272 males. Their self-control scores were used in order to select sixteen teams composed of high self-control members and sixteen teams composed of low self-control members.

Experimental Study

A total of thirty-two, 2-person teams were run, 16 of which were composed of high self-control members and 16 of low self-control members. The upper and lower quartiles of the questionnaire data gathered in the pilot study were used as cutoff scores. That is, low self-control was defined as a total self-control score of 4.5 or less corresponding to the 25th percentile of the sample. High self-control was defined as a total score of 36.5 or higher, corresponding to the top 25 percent of scores.

After obtaining informed consent, all teams were trained on a computer-based simulation of the team task (TANDEM) and required to perform the task until asymptotic performance was reached (three, 20-minute sessions, as determined by the pilot studies conducted for this purpose). Subjects then performed four, 10-minute test sessions. First, subjects performed such a task session to adapt them to the performance of 10-minute sessions (as opposed to 20-minute) without visible score. The baseline task session to be used as a comparison condition with subsequent stress sessions, was then performed. Subjects were then exposed to the two stress sessions presented in a within-groups design, such that all

subjects were exposed to both sessions. The order of the two stress sessions was counterbalanced across teams. Approximately 10-minutes passed between sessions as subjects completed questionnaires.

Stress was imposed in the form of the threat of shock. Just prior to the stress conditions, subjects were informed that they had reached the portion of the study in which shock would be introduced for the purpose of determining the impact of the shock on their ability to maintain effective task performance. Each team member was connected to the shock apparatus via an electrode on the index finger of the non-dominant hand. Prior to each stress condition, team members were instructed as to when they would be shocked. In the ambient stressor condition, the threat was described as a "random occurrence unrelated to any behavior on the subjects' part". On the other hand, in the performance-contingent stress condition, threat was described as "shock presented when the performance of the team falls below their previous average performance." It is important to note that subjects received feedback in the form of a team score displayed as part of the TANDEM task during skill acquisition. However, team scores were not displayed during the baseline and stress conditions. That is, since subjects were informed that shock was performance contingent during one of the stress conditions, it was necessary to keep the availability of feedback regarding their performance constant across the three task sessions of interest.

Immediately following task performance in each of the three conditions subjects were required to respond to three questionnaires: the state portion of the STAI, the Ways of Coping Questionnaire, and the social support questionnaire. Subjective stress (as measured by the STAI) was conceptualized as the mean reported anxiety score of teams' individual members and performance stress was considered as the team performance change from baseline under the stress conditions. Measures of social support were averaged in the same manner as the STAI. Following performance of the final session and completion of questionnaires subjects were debriefed and dismissed.

Results

Anxiety

In order to test hypotheses regarding anxiety differences as a function of self-control and stressor condition, a 3 X 2 mixed model analysis of covariance was computed with social support as the covariate. Results of this analysis indicated that social support failed to act as a significant covariate for either the self-control or stressor condition effects. Consequently, a 3 X 2 mixed model analysis of variance was conducted. This analysis yielded a significant main effect of self-

control, such that low self-control teams experienced higher anxiety than did teams composed of high self-control members $F(1,30) = 9.26$, $p < .05$. The eta squared value computed for this effect was 0.14. The analysis also yielded a significant main effect of trial, indicating that anxiety differed as a function of stressor condition $F(2,60) = 9.19$, $p < .05$. Subsequent tests indicated that teams' anxiety was higher in both stressor conditions than in the no-stress condition. However, anxiety did not differ significantly between the two stressor conditions. The eta squared value computed for the effect of stressor condition was 0.09. There was no significant interaction.

Performance

A multivariate analysis of covariance (MANCOVA) was performed on the four team performance measures in order to test hypotheses regarding team performance differences as a function of self-control and stressor condition. This analysis yielded no significant main effect of self-control or stressor condition, nor was there any significant interaction.

Because apriori hypotheses were made regarding performance differences with regard to self-control and stressor conditions, univariate analyses of covariance were also computed with team score, query time, number of items queried, and penalty points as dependent variables. Social support was not a significant covariate in any of these analyses, therefore, univariate analyses of variance were computed. Of these four analyses only a significant main effect of self-control for penalty points was revealed such that low self-control teams scored significantly more penalty points than did high self-control teams $F(1,30) = 6.13$, $p < .05$. The computed eta squared value for this effect was 0.08. No other significant main effect or interaction was found with regard to the performance variables.

Coping

Hypotheses regarding differences in subjective measures of coping as a function of self-control and stressor condition, were tested by computing mixed model analyses of variance with team averages of the measures of problem focused coping, and five measures of emotion focused (distancing, wishing, self isolation, positive thinking, and social support) as dependent variables. These analyses indicated a significant main effect of self-control $F(1,30) = 17.37$, $p < .001$ and stressor condition $F(2,60) = 4.21$, $p < .05$ for the problem focused coping dimension. The analysis indicated that low self-control teams used more problem focused coping than did high self-control teams. The eta squared value for this

effect was 0.24. Subsequent tests regarding the significant main effect of stressor condition indicated that more problem focused coping was used in the no stressor and performance contingent condition than within the ambient stressor condition. However, the performance contingent and no stressor conditions did not differ. The eta squared value for this effect was 0.04.

No significant main effect of self-control or stressor condition was found for any of the emotion focused dimensions. However, the analyses did indicate a non-hypothesized interaction of self-control and stressor condition for the self-isolation dimension of the coping inventory $F(2,60) = 3.67, p < .05$. Subsequent tests revealed that low self-control teams used more self isolation as an emotion focused coping strategy in the no stressor condition than high self-control teams, with no further self-control differences in either of the stressor conditions. Furthermore, low self-control teams used self isolation more in the no stressor condition than in the ambient stressor condition. However, there was no difference between the no stressor and performance contingent conditions for low or high self-control teams.

Manipulation Check

A paired samples t-test was computed with regard to subjects responses to two questions. Each of these questions asked subjects to report their perceived control in the ambient and performance contingent stressor conditions respectively. This analysis indicated that subjects perceived significantly more control in the performance contingent shock condition than within the ambient shock condition $t\ (63) = 12.24$, $p < .05$ (M = 75.0, 20.76).

Discussion

For the sake of clarity, this section will revisit and discuss the implications of each hypothesis originally posited regarding the three dependent variables; anxiety, coping, and performance.

Anxiety

It was originally hypothesized that high self-control teams would report less anxiety than low-self control teams. Support for this hypothesis was found. This finding is consistent with past research indicating that high self-control individuals

demonstrate greater tolerance of adverse conditions than low self-control individuals (Rosenbaum, 1990).

It was also hypothesized that state anxiety in the ambient stressor condition would be higher than in the performance contingent condition, but that state anxiety in the performance contingent condition would be significantly higher than in the baseline condition. This hypothesis received mixed support. Specifically, although anxiety was higher in both stressor conditions than within the no stressor condition, no difference was obtained between stressor conditions.

The rationale for differences in anxiety between stressor conditions was explained previously with regard to the control perceptions of persons exposed to either a controllable or uncontrollable stressor. That is, it was hypothesized that anxiety would be higher in the ambient stressor condition because that stressor was uncontrollable in comparison to the performance contingent stressor condition. In order to determine whether subjects perceived differences in control, a manipulation check was utilized. Specifically, subjects were asked to report their perceived control in each of the two stressor conditions. The analysis of these data indicated that subjects did perceive greater control in the performance contingent stressor condition than within the ambient stressor condition. Thus, the manipulation was effective with regard to instilling these altered control perceptions. However, there was no resulting difference in state anxiety.

Coping

It was hypothesized that teams composed of high self-control members would report different coping behaviors (problem vs. emotion focused), as assessed with the Ways of Coping Questionnaire, than low self-control teams. This hypothesis was partially supported in that high self-control teams used more problem focused coping than low self-control teams. This finding is consistent with past research which indicates that high self-control individuals utilize more task relevant coping than low self-control individuals (Rosenbaum, 1990).

Although problem focused coping differed as a function of self-control, there was no meaningful difference in emotion focused coping. A possible explanation for this finding relates to the salience of the task performance situation and the salience of the stressor. That is, the salience of the requirement for task performance in combination with the possibly low salience of the threat might have induced subjects to feel less compelled to utilize emotion focused coping than was previously hypothesized.

The finding that social support failed to serve as a significant covariate in relation to stressor condition was surprising given the literature indicating that

social support is an effective means of ameliorating, to some extent, the effects of stressors. Apparently, in the current laboratory context this measure did not accurately capture resources contributed across team members and conditions. Specifically, this might have been the case for two related reasons. First, the manipulation of threat might not have been salient enough to cause team members to feel the necessity to exchange resources. Thus, no social support differences needed to emerge to "buffer" these effects. Second, because team members were males brought together in the context of a laboratory setting, they might have been hesitant to offer and/or report the contribution of social support resources as assessed by the instrument used within this study.

Anecdotally, the subjects often joked between themselves regarding the more "emotional" items included on the Ways of Coping and social support measures. Perhaps these subjects were hesitant to respond truthfully regarding the more "emotional" items on the questionnaires. This might account, in part, for the failure to find a significant difference regarding emotion focused coping and social support.

Performance

Self-Control

With regard to team performance, it was hypothesized that teams composed of high self-control members would outperform teams composed of low self-control members as assessed by four TANDEM performance variables. Little support was indicated for this hypothesis, with no difference evidenced for score, query time or number. However, low self-control teams accumulated more penalty points than high self-control teams. This indicates that high self-control teams were more attentive to critical targets presented in the immediate vicinity of "ownship". A potential explanation for this difference in terms of self-control might be related to the nature of this performance measure. That is, because penalty points represent the loss of resources when targets are allowed to approach too closely, it is possible that this measure represents the extent to which low vs. high self-control teams respond to the demands of time-pressure. Specifically, it appears that high self-control teams are better able to recognize the salience of the targets approaching as threatening and to perform so as to minimize this threat. Although for the purposes of the current study, team score was a primary measure of interest, penalty points simulate a critical measure of performance in the operational environment. Specifically, it is obviously critical for teams in such settings as a command information center or fire-fighting to be able to

respond quickly, as well as correctly. It is possible that level of self-control is a significant predictor of the ability to respond effectively to time-pressure.

Stress

It was also hypothesized that, 1) team performance in the ambient stress condition would be inferior to that of performance in the performance contingent condition, which would be significantly worse than the baseline condition and, 2) that a significant interaction (condition by self-control) would be evidenced such that high self-control teams would perform better in the ambient stress condition than low self-control teams, with a smaller difference between low and high self-control team performance in the performance contingent condition. Neither of these hypotheses were supported.

Although it was expected that performance differences might be found within the current study, past literature regarding individuals, and their performance under stress has at times found evidence of performance degradation with stressor exposure, and at other times evidence of performance facilitation. Thus, it is reasonable to expect the relationship between stress and team performance to be complex, given that both intra- and inter-individual processes and the complexity of the task to be performed must be considered.

There is some literature to suggest that the performance of teams degrades with stressor exposure (Driskell & Salas, 1991). However, in the case of the study by Driskell and Salas, the stressor was highly threatening (i.e., possible tear gas exposure) and the task performed was highly ambiguous. Other research has been equivocal regarding teams and their performance while exposed to such stressors as workload, ambiguity, and time pressure. For example, Urban, Bowers, Monday, and Morgan, (1995) investigated the impact of workload on performance and found no overall effects of workload. Other research (Weaver et al., 1994) has investigated the effect of ambiguity and time-pressure. The study by Weaver and her colleagues found no effects of ambiguity on performance. However, time-pressure was associated with degraded performance. Conversely, Serfaty, Entin, and Volpe (1993) who also investigated the effects of time-pressure and ambiguity, found no significant performance differences for time-pressure, although performance was degraded by increased ambiguity. Thus, prior research regarding such task-related stressors has been equivocal.

Within the current study, teams reported changes in anxiety and coping with altered situational demands. However, no performance decrement was revealed. One explanation is that the variability of team task performance was already so great that the manipulation was ineffective in producing any significant change within the stressor conditions. Another possible explanation for this finding is related to the relatively low difficulty level of the task performed by teams in

this study. It has been argued that the less attention a task demands, the less vulnerable it is to the performance effects of stress (Hancock, 1981). Within the context of the current study, the task procedure remained unchanged. That is, although the presentation of targets was dynamic, the procedure for determining the necessary outcome remained the same. Thus, this behavior became relatively well practiced. In addition, the task was designed so that teams had the capability to find "the right answer" if they followed the prescribed procedure. Thus, in these respects, the task was relatively easy for a decision making task.

Another possible explanation for failure to find performance effects might lie within the teams' performance processes. In other words, it is possible that teams were able to adapt their process in order to prevent the occurrence of performance decrements. In fact, it has been argued that it is critical to consider stress at the process level of teams in order to gain a thorough understanding of the impact of stressors on team performance (Morgan & Bowers, 1995). Consequently, it appears that there is a need for further research in order to attempt to explicate these relationships between stressor exposure and team performance.

Directions for Further Research

In order to better understand the effects of stress on teams, team performance, and team interactions, there appear to be several areas of research where valuable knowledge is still needed. For example, research that utilizes highly salient stressors, stressors that more closely approximate real world situations, would yield valuable information. Future research needs to be conducted in settings which allow the manipulation of such stressors.

Future research should also investigate the effects of stressors presented earlier in training. Although there is clearly a need to gain an understanding of stress in order to maximize performance in operational settings, perhaps an understanding of the mechanisms by which stress functions would be best gained at this juncture by investigating the effects of stressors and the processes involved (e.g., coping) with participants who are relatively inexperienced. There is some research evidence to suggest that the presentation of stressors late in training will have a less deleterious effect on performance than stressors introduced early in training (Ryan, 1961). This research might prove valuable in the design and conduct of research which would provide information regarding stressor effects in operational settings with experienced operators.

The current study represents a relatively novel approach to studying the effects of stressors and the degree to which such exposures might be ameliorated by coping resources originating intra- and inter-individually. It appears that the

modes of measurement suggested by Lazarus and Folkman's treatment of the stress phenomenon might be valuable in gaining further understanding of team process and performance under stressful conditions. That is, it might be useful to consider other individual and team coping resources (e.g., cohesion) within the context of other types of team tasks. It may also prove useful to determine the relative efficacy of such coping resources as social support and emotion focused coping via another assessment approach. For example, behavioral approaches to measurement might be useful in order to minimize problems such as shared variance and hesitancy of subjects to report particular types of feelings and behaviors.

Given that past team research has suggested the criticality of team processes as related to team performance, future research should include such team process measures as communication. Because results of the current study indicated differences in terms of coping, it might prove beneficial to investigate the extent to which further evidence of coping might be found in communication behaviors. Subjective measures of coping as obtained within this study might yield less information relevant to team performance than coping measures which capture the dynamics of interpersonal interaction. That is, what team members report doing individually in terms of coping might not be as relevant to team performance as what team members are observed to do collectively. Perhaps the identification of such behaviors might be useful in the development of stress inoculation training interventions relevant for operational teams. Further research regarding teams and stress could attempt to address some of these issues.

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What's Happened Since Project A: The Future Career Force[1]

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ABSTRACT

In 1982, a program of research was initiated to improve the Army's selection, classification, reenlistment and promotion systems. This program was conducted in two phases. The first phase, known as Project A, was completed in 1989; the second, known as Building the Career Force, in 1995. During Project A, a concurrent validation was completed which provided information on the structure of initial entry performance and the relationship between a variety of predictor constructs and performance dimensions. Also, during Project A, an effort was initiated to link these predictors with both entry level and early supervisory performance in a longitudinal fashion. This paper describes the results of this longitudinal validation, completed under the Career Force project. It describes the generation of a model of early supervisory performance. It shows how the powerful relationship between cognitive aptitude and job proficiency demonstrated in Project A held across time, organizational levels and cohorts, but that concurrent relationships between temperament and performance dimensions of a "will do" nature declined over time. Relationships between early and later career performance supported the notion that past performance predicts future performance on comparable performance dimensions. Overall, Career Force has considerably extended our knowledge of the nature of performance, of the relationship between individual differences

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and job performance, and of the comparison of validity results obtained from a longitudinal design with those obtained from a concurrent design.

In 1982, Project A was launched. It was an effort to improve the Army's selection and classification system, but that statement does not fully capture its impact and scale. It was described by Hakel in the 1986 *Annual Review of Psychology* as the "most significant effort in the measurement and interpretation of human differences yet undertaken (p. 373)." Its major accomplishments were summarized in a 1990 special issue of Personnel Psychology, an issue which earned its contributors a scholarly achievement award from the Academy of Management.

Now, six years after the publication of that special issue, it is time to reveal what has happened since Project A. For those who thought the story ended with the completion of Project A, it may come as a surprise to learn that this project was just the first stage of a two-part Soldier Selection research program and that the second stage, known as Building the Career Force, was just recently completed. In the course of this follow-up effort, a longitudinal design has been completed which confirmed some of the Project A results and expanded upon others. Some of the more interesting questions that could not be answered in 1990 can now be addressed. These questions include the following:

1. How do the components of entry level performance differ from those of first level supervisory performance?
2. How well do measures of individual differences predict performance at different career stages?
3. How do concurrent and longitudinal validation results based on essentially the same predictor and criterion measures differ?
4. How well does early career performance predict later performance?

Before we explore the answers to these questions, we need to go back in time to describe the circumstances that led to the Soldier Selection projects. At the time of the initiation of Project A, there was considerable concern about the qualifications of entering enlisted soldiers. Problems concerning the norming of the Armed Services Vocational Aptitude Battery, or ASVAB, used to select and classify all enlisted soldiers, had surfaced, indicating that those entering the Army between 1976 and 1980 represented a lower segment of the population on this measure than originally believed. Congress wanted to know what this meant in terms of job performance (Shields & Hanser, 1990).

The Soldier Selection research program was launched as part of a Joint Service effort to link enlistment standards to job performance. However, this program went further than that. A variety of new equipment systems were soon to be fielded, and there was a concern that soldiers be qualified to effectively use these

systems. There was interest not just in the verbal, quantitative, and information types of measures represented in the ASVAB, but in spatial, psychomotor, temperament, and interest measures as well.

Thus, the first objective of the research program was to link selection to job performance by developing new entry tests and linking them and the ASVAB to new performance measures. The second objective was to link selection, classification, and job performance to career progression in order to maximize performance at higher levels as well as at initial entry.

Project A, which lasted from 1982 to 1989 and focused on initial entry performance, was the first project in this research program. Project A looked at the relationship between the ASVAB and job performance. Also in Project A, new tests were developed and concurrently linked to performance.

Materials and Methods: Soldier Selection Research

Design: Overview

Two designs, as we will examine more closely later, were initiated in Project A. One was concurrent and one was longitudinal. The results that have been reported from Project A have all been from the concurrent design. When Project A was completed, data from the longitudinal data collections had been partially collected but not analyzed nor reported. Thus, for purposes of convenience, we will associate all findings from the longitudinal sample with Career Force.

The concurrent design involved the concurrent collection of data from the new predictors and performance measures on 9430 soldiers who had typically served in the Army for a period of 12 to 24 months. A smaller sample of 4039 was used in the validity analyses which will be discussed later. The amount of missing data and the jobs from which the data were drawn were two factors determining which cases were used in this smaller sample (Young, Houston, Harris, Hoffman, & Wise, 1990). In addition to the data that were collected in the field during the course of this project, ASVAB data which had been collected at entry were used in the analyses. Thus, although we will continue to refer to this as the concurrent validation, it was more precisely a mixed design, with the ASVAB linked to job performance in a longitudinal fashion (the overall design for the Project A/Career Force projects is described in Campbell & Zook, 1994c).

Twenty-two jobs were examined in Project A and Career Force. However, for a substantial subset of these jobs, only limited criterion information was collected. This was done by design, so that it would be possible to compare analyses based on a partial set of criterion measures with analyses based on a more comprehensive set. For the most part, the analyses that will be examined in this paper were

based on nine jobs: infantryman, cannon crewman, tank crewman, radio teletype operator, vehicle generator mechanic, administrative specialist, motor transport operator, medical care specialist, and military police. These nine jobs represent a reasonable cross-section of the full set of the hundreds of Army jobs. They include combat jobs and combat support jobs. They include jobs which reasonably represent African Americans and females, as well as those combat jobs which females are by policy excluded from. They were by necessity jobs which were heavily populated so that statistical analyses could reasonably be conducted (see Campbell, 1987, for a discussion of the process of selecting jobs for this research effort).

Predictor Measures

The purposes of this research dictated that the list of entry predictors examined would include ASVAB. The ASVAB consists of ten subtests, which are combined into ten different composites. Factor analyses have consistently identified four factors: verbal, quantitative, technical, and speed (Kass, Mitchell, Grafton, & Wing, 1983; Peterson, et al., 1990).

The approach to identifying additional predictors incorporated the following elements. First, there was no attempt to replicate the content domain of the ASVAB. The focus was on content categories which could best supplement the ASVAB in predicting job performance. A comprehensive literature review, followed by extensive pre-testing, resulted in the generation of 62 measures, which were reduced to 27 composites in the following categories: spatial, computer, temperament/biographical, job preferences, and career interests. Six spatial tests, such as Map, Maze, and Assembling Objects, eventually reduced to a single composite. Psychomotor and perceptual attributes were assessed through eight computer test composites. A variety of temperament scales, such as conscientiousness and cooperativeness, were reduced to seven composites in an instrument named the Assessment of Background and Life Experiences, or ABLE. Preferences for particular types of job outcomes, such as job security and autonomy, were measured in an instrument known as the Job Orientation Blank (JOB). Career interests were measured in the Army Vocational Interest Examination, or AVOICE. This was based on an Air Force instrument known as the VOICE (Peterson, et al., 1990).

Entry Level Performance Measures

One of the prominent features of Project A was its historically comprehensive treatment of the criterion space. Performance measures included hands-on tests,

job knowledge tests, rating scales, and administrative measures. A series of exploratory and quasi-confirmatory analyses resulted in the identification of five substantive factors. The first two dimensions, Core Technical Proficiency and General Soldiering Proficiency, have been described as "can do" dimensions, and assess individual job proficiency. They were based on hands-on and job knowledge tests. The last three, Effort and Leadership, Personal Discipline, and Physical Fitness and Military Bearing, tended to be more "will do", or motivational in nature. They were based on ratings and self-report of information contained in administrative records, such as awards and certificates and physical readiness scores (Campbell, McHenry, & Wise, 1990).

Project A Results: Brief Summary

We will not attempt to comprehensively describe here the results from Project A. These will be summarized later in this paper in the context of a comparison of Project A and Career Force findings. However, a few points will be mentioned here. First, ASVAB was found to have impressively high validity for predicting the "can do" performance dimensions. The spatial tests added a small increment to the prediction of these dimensions. The findings with respect to the "will do" dimensions were somewhat different. ASVAB was but a moderately effective predictor of these dimensions. Adding composites from the ABLE, the temperament instrument, to the ASVAB enhanced the prediction of "will do" performance substantially.

Career Force: Materials and Methods

As the title of this paper indicates, its principal focus is what has happened since Project A. The follow-up effort, Career Force, lasted from 1989 to 1995 and focused on early supervisory performance. While Project A told us something about both ASVAB and the new predictors, Career Force was designed to tell us how to best combine ASVAB and the new predictors for selection and classification. Also, by following soldiers into their second tour, it has given us a basis for building an improved noncommissioned officer (NCO) corps through selection, classification, reenlistment, and promotion decisions.

Subjects

Now that Career Force is over, we can complete the picture that was partially painted in Project A. Results from four new data collection points have been added. First, soldiers from the concurrent validation were followed into the second

tour. The remainder of the results, and those which we will concentrate on here, are from the longitudinal validation. A total of 49397 soldiers were tested at entry in 1986 and 1987 on the new predictors described earlier. Performance was measured at three points—end of training, in the soldier's first tour, and three to six years after entry, which in many cases represented the soldier's first supervisory assignment, although a large number of this group still had not reached NCO status. Training data were collected on 34305 soldiers (Campbell & Zook, 1991). Then 11266 were tested about 12-24 months after entry on first tour performance in 1988 and 1989 (Campbell & Zook, 1990). The first tour performance measures were those described earlier. Finally, in 1991 and 1992, 1595 soldiers were followed into the second tour, where performance measures were again administered (Campbell & Zook, 1994b).

In a world ideally suited for this research project, each soldier would have been tested at each stage—entry, end of training, first tour and second tour. However, soldiers who had been tested at earlier stages were not always available for testing at later stages, and there was a compelling need to have large sample sizes for certain analyses which did not involve linking measures across all career stages. Thus, at each stage beyond initial entry, the data collection strategy involved a series of compromises between maximizing total sample size and maximizing the number of soldiers who met all project criteria, and the number of soldiers who were ultimately available for any particular analysis was a function of how this strategy was executed.

For the analyses reported here, sample sizes were constrained by two considerations. First, analyses were limited to those jobs for which the full set of criterion measures were administered. For entry level jobs and for end of training, these were, for all practical purposes, the nine jobs listed above. For second tour analyses, only seven jobs were included, with radio teletype operator and motor transport operator excluded because of the small sample sizes available for these jobs.

The second constraint was that, for the end of training validity analyses, for which 4039 cases were examined, and for entry level validation, where the total sample size for analysis was 3090, soldiers were required to have complete predictor and criterion data. Complete predictor data were not required for the analyses linking entry predictors with first level supervisory performance measures. For those analyses, sample sizes varied from 810 to 1224 depending on the predictor set being evaluated.

Training Performance Measures

Two types of measures of training performance were administered—knowledge tests and rating scales. These measures yielded dimensions very similar to those identified in first tour. Just as there was a core technical first tour dimension,

there was a technical school knowledge dimension based on written job specific test items. School knowledge basic, based on written common task test items, was comparable to general soldiering proficiency. The will do dimensions, based on ratings, were comparable to the will do first tour dimensions, with the addition of one new "will do" dimension in the training environment, "leadership potential (Campbell & Zook, 1990)."

Entry Level Performance Measures

The entry level performance measures administered in the longitudinal validation ("Career Force" measures) were virtually the same as those administered in the concurrent validation. The model of first tour performance generated in the longitudinal validation replicated the concurrent validation model (Campbell & Zook, 1994a).

Supervisory Level Performance Measures

As for the entry level, supervisory level measures included hands-on and job knowledge tests, ratings, and administrative measures. In addition, they included a written Situational Judgment Test requiring a response to a supervisory situation, and special ratings provided in the context of training and counseling role play exercises. These measures were grouped into six dimensions. Four dimensions, core technical proficiency, general soldiering proficiency, personal discipline, and physical fitness/military bearing, were strikingly similar to their identically-named entry level counterparts. A fifth dimension, achievement and effort, was also similar to a first tour dimension, effort and leadership. The principal difference was the addition of a supervisory level sixth dimension, leadership, represented by leadership performance ratings, performance on the role play exercises, and scores on the Situational Judgment Test. The supervisory model presents, rather than a can do and will do division, a can do, will do and leadership division (Campbell & Zook, 1994b).

Analyses

Multiple correlations between each set of predictor scores and the substantive factor scores were computed for training performance, entry level performance, and first level supervisory performance. Results were (1) corrected for multivariate range restriction (Lord & Novick, 1968) on the ASVAB subtests using the intercorrelation matrix among the subtests in the 1980 Youth Population (Department of Defense, 1982), and (2) adjusted for shrinkage using Rozeboom's (1978) Formula 8. Results were computed separately by job and then averaged.

Incremental validities for each additional predictor set over the ASVAB were

Table 1.—Average Multiple *R*s and Increments in Multiple *R*s over ASVAB for Predictor Sets Used in End of Training Sample

Criterion	ASVAB	Spatial	Computer	JOB	ABLE	AVOICE
Tech Know.	76	63 (01)	61 (01)	41	33	44
Basic Know.	68	57 (01)	57	38	30	37
Eff/Tech Skill	41	35 (01)	36 (01)	24	19 (03)	22
Leadership	30	24	28 (01)	18	22 (05)	17
Discipline	25	22	21	09	19 (09)	11
Fitness/Brng	14	05	11 (03)	05 (01)	29 (17)	07 (01)

Note: All values in Tables 1–5 should be interpreted as decimals but are presented as integers for ease of reading (e.g., the first value in the ASVAB column is actually 0.76, but is presented as 76. Numbers in parentheses represent incremental value for that predictor set over ASVAB. For example, the first value in the Spatial column is 0.63. Spatial tests provide an increment of .01 over the ASVAB multiple *R* of 0.76. Thus, when spatial tests are combined with the ASVAB, the multiple *R* increases to 0.77. Only incremental values exceeding zero are shown. Data presented are from *Building and Retaining the Career Force: New Procedures for Accessing and Assigning Army Enlisted Personnel: Annual Report, 1991 Fiscal Year* by J. P. Campbell and L. M. Zook (Eds.), pages 41 and 49. Adapted with permission.

then computed, using the same range restriction and shrinkage adjustments, and averaging across jobs as before.

Career Force Results

Now let us turn to the Career Force validity results, beginning with the prediction of training performance. These results are summarized in Table 1. Multiple regression coefficients are provided for each predictor composite linked with each criterion dimension. There is a pattern that began to emerge in Project A which, with some variations, we will find to pervade the Career Force results as well. First, there was the impressive strength of the cognitive measures in predicting can do performance. This was most evident with respect to the ASVAB, although the predictive validities of the spatial and computer composites were nearly as high.

The cognitive validities dropped for the will do dimensions. The validities of the noncognitive predictors, JOB, ABLE and AVOICE, also dropped from can do to will do dimensions. ASVAB was the best predictor of all dimensions except fitness and bearing, where ABLE emerged as the strongest predictor.

Table 1 also shows incremental validities for each predictor set over ASVAB. While the ABLE validities tended to be modest across all dimensions, ABLE composites collectively clearly emerged as the instrument providing the greatest incremental validity over the ASVAB for all will do dimensions, particularly fitness and bearing (Campbell & Zook, 1994a).

Now we look at the validities and incremental validities for entry level perfor-

Table 2.—Average Multiple *R*s and Increments in Multiple *R*s over ASVAB for Predictor Sets Used for Entry Level Sample

Criterion	ASVAB	Spatial	Computer	JOB	ABLE	AVOICE
Core Tech	62	57 (01)	47	29	21	38
Gen. Soldier	66	64 (02)	55	29	23	37
Effort/Ldrship	37	32	29	18	13	17
Discipline	17	14	10	06	14 (06)	05
Fitness/Brng	16	10	07	06 (01)	27 (14)	05

Note: Numbers in parentheses represent incremental value for that predictor set over ASVAB. Only incremental values exceeding zero are shown. Adapted from *Building and Retaining the Career Force: New Procedures for Accessing and Assigning Army Enlisted Personnel: Annual Report, 1991 Fiscal Year* by J. P. Campbell and L. M. Zook (Eds.), pages 164 and 171. Adapted with permission.

mance, shown in Table 2. The pattern was quite similar to that for training performance, with the cognitive measures providing impressive prediction of can do performance and all measures generally providing better prediction of can do than will do performance. In general, the entry level validities tended to be somewhat lower than the training performance validities. Note that the ABLE composites still provided the most incremental validity over ASVAB, although the increments were smaller than in the case of training performance (Campbell & Zook, 1994a).

At the completion of Career Force, we had the opportunity to compare concurrent and longitudinal validities for prediction of initial entry performance. In order to make these comparisons, it was necessary to recompute the longitudinal validities using the Claudy (1978) adjustment for shrinkage, as this was the procedure used in Project A for computing the concurrent validities. Again, we should note that the administration of the ASVAB was necessarily longitudinal in both cases, while for all other measures the first administration was concurrent. The comparisons are presented in Table 3. Because of the use of the Claudy adjustment for these analyses, the validities shown for the longitudinal validation are slightly different from those shown in Table 2. The most remarkable feature of Table 3 is the consistency across both data collections for the cognitive tests. The spatial and computer tests generally predicted as well, or almost as well, in the longitudinal as in the concurrent administration. Curiously, all cognitive measures predicted effort and leadership more effectively in the longitudinal than in the concurrent administration.

Now consider the same comparison for the non-cognitive measures. These measures tended to predict can do performance equally effectively in the concurrent and longitudinal validations. This was not the case, however, for prediction of will do performance. Here there was a consistent decline, particularly for the temperament instrument, ABLE. The incremental validities for ABLE over ASVAB also show a consistent decline in the longitudinal relative to the concur-

Table 3.—Comparison of Entry Level Concurrent (Project A (Prj. A)) and Longitudinal (Career Force (CF)) Validities

	Cognitive Predictors					
	ASVAB		Spatial		Computer	
Criterion	Prj. A	CF	Prj. A	CF	Prj. A	CF
Core Tech.	63	63	56	57	53	50
Gen. Soldier	65	67	63	64	57	57
Effort/Ldrship	31	39	25	32	26	34
Discipline	16	22	12	14	12	15
Fitness/Brng	20	21	10	10	11	17

	Non-Cognitive Predictors					
	JOB		ABLE		AVOICE	
Criterion	Prj. A	CF	Prj. A	CF	Prj. A	CF
Core Tech.	29	31	26	27	35	41
Gen. Soldier	30	32	25	29	34	40
Effort/Ldrship	19	22	33	20	24	25
Discipline	11	11	32	22	13	11
Fitness/Brng	11	12	37	31	12	15

Note: Adapted from *Building and Retaining the Career Force: New Procedures for Accessing and Assigning Army Enlisted Personnel: Annual Report, 1991 Fiscal Year* by J. P. Campbell and L. M. Zook (Eds.), page 179. Adapted with permission.

rent validation. This decline is particularly evident on the effort and leadership dimension (Campbell & Zook, 1994a).

Finally, we look at the validity of entry-level measures for predicting performance three to six years in the future. There is a fairly pervasive point of view that the longer a person is on the job, the less important test scores administered at the point of entry become. We now have results, shown in Table 4 (Campbell & Zook, 1994c), that suggest that this point of view needs to be re-examined. All predictors administered at entry predicted job specific technical proficiency in the second tour as well or better than they predicted this measure in the first tour. There was a decrement, but only a small one, with respect to general soldiering proficiency. On the other hand, there were several instances where validities for predicting will do performance declined, particularly in the prediction of achievement and effort.

Another striking finding was the strength of all entry measures for predicting the leadership dimension. The pattern of these relationships was very similar to the pattern of validities with respect to can do performance. However, the measures of leadership were very different from the measures of technical proficiency.

As Table 4 shows, once ASVAB was accounted for, the additional predictive validity contributed by any entry predictor to second tour performance was very

Table 4.—Average Multiple *R*s and Increments in Multiple *R*s over ASVAB for First Level Supervisory Sample

Criterion	ASVAB	Spatial	Computer	JOB	ABLE	AVOICE
Core Tech.	64	57	53	33	24	41
Gen. Soldier	63	58 (01)	48	28	19	29
Ach/Effort	29	27 (02)	09	07	13	09
Leadership	63	55	49	34	34 (01)	35
Discipline	15	15	12	03	06	06
Fitness/Brng	16	13	03	07	17 (05)	09

Note: Numbers in parentheses represent incremental value for that predictor set over ASVAB. Only incremental values exceeding zero are shown. Adapted from *Building and Retaining the Career Force: New Procedures for Accessing and Assigning Army Enlisted Personnel: Annual Report, 1993 Fiscal Year,* by J. P. Campbell and L. M. Zook (Eds.), pages 132, 140, and 141. Adapted with permission.

limited. ABLE still provided some incremental validity to the prediction of fitness and bearing, and added one point to leadership, but these increments were reduced from those observed for first tour criteria.

Now we look at another question: How well does early career performance predict later career performance? We had an opportunity to look at this question twice, once in the concurrent validation, which we will refer to here as the "Project A validation sample," and once in the longitudinal validation, which will be referred to as the "Career Force validation sample." Table 5 shows the results from the Career Force sample, corrected for range restriction. The bivariate correlational values along the diagonal, where similar first and second tour performance dimensions were linked, were reasonably high, representing good convergent validity. The off-diagonal values tended to be lower, often substantially lower, representing good discriminant validity.

The results from Project A, where the samples were smaller (n = 102-121

Table 5.—Prediction of Performance from Prior Performance: Career Force Validation Sample

	First Supervisory Level				
Entry Level	CT[a]	GS[b]	AE[c]	Disc[d]	FB[e]
Core Tech	**44**	$\underline{51}$	28	−04	−03
Gen. Soldier	41	**57**	34	04	−01
Effort/Ldrship	25	22	**47**	12	22
Discipline	08	09	$\underline{29}$	**26**	14
Fitness/Brng	02	−01	26	17	**46**

Note: Sample sizes for bivariate correlations ranged from 322 to 412. Diagonal values are shown in boldface. Off-diagonal values which are larger than the corresponding diagonal value are underlined. From *Building and Retaining the Career Force: New Procedures for Accessing and Assigning Army Enlisted Personnel: Annual Report, 1993,* by J. P. Campbell and L. M. Zook (Eds.), page 161. Adapted with permission.
[a] Core Technical Proficiency [b] General Soldiering Profociency [c] Achievement and Effort [d] Personal Discipline [e] Fitness and Bearing

for the bivariate correlations), were similar. Here, again, a correction for range restriction was used. Values along the diagonal ranged from 0.26 (discipline) to 0.48 (fitness and bearing). Two off-diagonal values involving comparison between general soldiering with core technical proficiency were particularly high (entry level general soldiering with supervisory core technical proficiency r = 0.47; entry level core technical proficiency with supervisory general soldiering r = 0.48), as well as one between entry level general soldiering and supervisory effort and achievement (r = 0.36), but otherwise off-diagonal values were consistently lower than diagonal values (Campbell & Zook, 1994c).

Discussion

Four Research Questions

Now let us return to the questions posed at the beginning of this paper. First, the question of components of performance: How do the models of performance compare at early and later stages in the soldier's career? The results suggest that the model for initial entry performance represents a foundation upon which the soldier can build by adding new responsibilities at the first supervisory stage. The old responsibilities do not disappear: the technical and motivational dimensions remain important. However, a new leadership dimension appears, adding to the scope of the soldier's responsibilities.

Next is the question of how well individual difference measures predict performance at different career stages. The most striking results were obtained with the cognitive measures. We knew prior to Project A that cognitive measures predicted soldier performance at the early, training stage from such research as that conducted by Maier and Fuchs (1973), and we began to appreciate in the course of Project A the strength of these measures for predicting job performance in the soldier's initial tour (McHenry, Hough, Toquam, Hanson, & Ashworth, 1990). We now have information that strengthens this conclusion and which, additionally, shows that these measures retain their predictive power three to six years out, when the individual has generally assumed a higher level of responsibility.

The issues associated with non-cognitive measures are more complex. These measures did not predict performance at a particularly high level, but the temperament measure ABLE more consistently provided incremental validity in combination with ASVAB than any other new predictor. Both the ABLE's zero order validities and incremental validities with respect to will do performance declined over time, but this decline was not observed with respect to technical proficiency criteria. We believe that temperament measures and biographical measures which tap temperament constructs have promise for predicting performance, and Project

A and Career Force have stimulated follow-on research efforts by the Army Research Institute (ARI) to explore this promise in greater depth.

The third question is: How do concurrent and longitudinal results differ? The biggest surprise is how little they differed in this research, particularly when cognitive predictors were at issue. The decline in predictive validity for the non-cognitive predictors in the longitudinal validation may be a subset of the larger issue of the decrement in the validity of such measures over time. Although many explanations have been explored for this decline (Campbell & Zook, 1994a; White & Moss, 1995), there does not appear to be a single one which totally accounts for this phenomenon.

The fourth and final question is how well early career performance predicts later performance. The generally high level of convergent validity is encouraging and consistent with expectations. The consistency of performance over time has potential payoffs in informing promotion decisions. The value of performance information is likely to be greatest with respect to those will do dimensions that are so difficult to predict by other means.

Additional Implications

A few other results from this research are worth noting. We have noted the predictive power of cognitive measures in several contexts. There is a remarkable consistency of the validity of cognitive measures in at least three respects: across time, across organizational levels, and across cohorts. The results have supported ASVAB as an initial entry selection tool and have provided evidence that it has perhaps greater value as a predictor of leadership performance than previously suspected.

Also, this research has shown that spatial tests can add small, pervasive increments for "can do" criteria. Despite the predictive power of the current ASVAB, the Services have agreed to add a new spatial test from Project A, Assembling Objects, to this joint service battery, in part because of evidence of its incremental validity. Not since the ASVAB was introduced in 1976 has another test presenting a new content category passed the many hurdles required for such a decision.

The Career Force results, in combination with the Project A results, have been used by Campbell and others (Campbell, 1994; Campbell, McCloy, Oppler, & Sager, 1992) to define a generalized multiple factor model of performance. The Career Force results confirmed the factors identified in Project A and expanded upon them to incorporate leadership.

The Career Force findings also provide guidance to those facing the challenge of whether to be satisfied with a concurrent validation design or whether to invest the additional time and resources required to conduct a longitudinal design. They provide some support for using a concurrent design to link cognitive predictors

with proficiency criteria. As the predictors and criteria get softer, however, the presumption that concurrent validities can substitute for longitudinal gets more difficult to defend.

The Career Force results have tempered somewhat our enthusiasm for temperament measures, but they have by no means caused us to close the door on such measures. At ARI, we have investigated temperament and biographical measures in a variety of contexts, and have consistently found encouraging results (Mael & White, 1994; White & Kilcullen, 1992). However, the results here suggest caution in using temperament measures to make long-term predictions. We have begun to conduct investigations examining results by item type. White and Moss (1995) found that for items judged as likely to be influenced by one's experiences in the Army, concurrent validities were higher than predictive validities, but for items classified as low on this dimension of organizational influence, concurrent and predictive validities were comparable.

The encouraging concurrent validities for ABLE from Project A should not be disregarded, as they may be particularly relevant when one is interested in obtaining measures relating to one's current job performance. The White and Moss findings suggest that careful attention to the linkage between temperament items and the organizational context in which such items are administered could result in temperament instruments with enhanced long-term utility.

Some of the most interesting findings from this research have to do with the prediction of junior level leadership. To fully appreciate these findings, we need to first examine how leadership was measured in this project. Leadership was identified as a separate factor, rather than encompassing all tasks the leader performed. Multiple methods of measuring leadership were employed, including ratings of job performance on leader dimensions, ratings of performance on role play exercises, and written responses to hypothetical leadership situations. The measures were based on extensive, exhaustive, and multi-method job analyses. To say that they were carefully developed is an understatement.

The findings indicated that, to some extent, everything predicted leadership. Both cognitive and non-cognitive measures did so, at levels from 0.34 to 0.63. The most impressive predictor of leadership was a cognitive test battery, the ASVAB. ASVAB not only predicted leadership well, it predicted it at virtually the same level as it predicted job proficiency. It is probably unwise to draw too many conclusions from a single finding, particularly when many soldiers in the supervisory sample in this research were not formally required to exercise supervisory responsibilities, but this finding does at least suggest that, at the first supervisory level, leadership is perhaps more closely linked to conventional measures of cognitive aptitude than might have been suspected.

The findings with respect to performance as a predictor are closely tied with

the performance modeling results. It is not enough to say that past performance predicts future performance—rather past performance on a particular dimension predicts future performance on that dimension, but not necessarily on other dimensions.

Finally, what are the implications for Army personnel selection and management? First, we have re-affirmed that the ASVAB is a good test, in the sense that it does what it is supposed to do—predict performance—and that the Army should continue to use it. Project A generated this finding; Career Force confirmed it. Second, we have generated further evidence of the incremental value of spatial tests in predicting technical performance, a finding that complements research showing that spatial and psychomotor tests are good predictors of such specialized military tasks as tank and anti-tank gunnery (Busciglio, Silva, & C. Walker, 1990; Grafton, Czarnolewski, & Smith, 1988; Graham, 1988; Silva, 1989; Smith & Graham, 1987; Smith & M. Walker, 1988). These results, in conjunction with results from a joint service project (see, for example, Wolfe, Alderton, Larson & Held, 1995 for a discussion of this project) and from a Marine Corps project (Carey, 1994) helped stimulate the Department of Defense to begin limited administration of Assembling Objects in an operational context, with plans for expanded administration in the future.

Third, we have developed a better understanding of the potential value of temperament measures, which we have begun at ARI to evaluate for use in limited operational contexts and are exploring for more extended use. Finally, we have gained a better understanding of which measures of present performance are promising candidates for use in promotion decisions, an understanding we plan to apply in future ARI research on the enlisted promotion system.

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Gender Differences in Human Abilities: Can Practice Moderate Results?

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ABSTRACT

The purpose of this review is threefold. First, we review the evidence regarding sex differences in perceptual, cognitive, and motor skills in general. Then we focus on gender differences in spatial abilities, an area where there are consistent and pervasive differences between males and females. The nature of the differences are explored, including possible reasons why these differences exist and whether differential performance on spatial tasks is moderated by practice. Experimental evidence indicates some malleability of performance through practice. These findings have implications for the future of women operating in an increasingly technological world.

Cognitive Differences

Systematic attempts to draw conclusions about similarities and differences between men and women achieved major prominence in the 1970's with the publication of Maccoby and Jacklin's (1974) narrative account of past research, "The Psychology of Sex Differences", which maintained that the sexes differed in several aspects of intellectual abilities (namely, verbal, quantitative, and spatial abilities) and in aggression. After the mid 80's, meta-analyses became the preferred method of research, providing a quantitative comparison between male and female behavior across many studies in terms of effect size (or d) which expresses the sex difference in units of the study's standard deviation.

To understand whether sex-correlated differences are small, medium, or large, it is helpful to keep in mind some general standards of comparison. Cohen's

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Table 1.—Largest Sex Differences (Males Superior)

Throw Velocity	2.18
Throw Distance	1.98
Aggression	.50
Mathematical Reasoning	.44
Proportional Reasoning	.44
Activity Level	.48
Spatial ability	.49
Spatial ability	.45
Mental Rotation	.73
Spatial visualization	.13

(1977) guidelines are expressed in terms of a difference, or d metric, where 0.20 is a small effect; 0.50 is a moderate effect; and 0.80 is a large effect. Medium effect sizes correspond to group differences that would be apparent to the naked eye, and large differences can be very readily perceived (Eagly, 1995). However, it is important to note that even findings that are relatively large produce distributions that substantially overlap. Using the d metric, it is clear that some sex-difference findings are quite large (about 0.80). These large effects occur with respect to at least one test of cognitive abilities (a test of mental rotation) and some physical abilities, such as throwing a ball (see Table 1). One researcher (Deaux, 1984) suggested that 5% of explained variance in a specific variable is an upper boundary for sex differences. Differences of this boundary magnitude and their mean effect sizes include: spatial ability, .45 (Hyde, 1981); aggression, .50 (Hyde, 1984); mathematical reasoning, .44 (Rossi, 1983); proportional reasoning, .48 (Meehan, 1984), and activity level, .49 (Eaton & Enns, 1986). Other syntheses have shown male superiority in motor behaviors, such as reaction time, flexibility, throw distance, and grip strength (Eaton & Enns, 1986; J. R. Thomas & French, 1985.)

But are these differences "real?" Or are they diminishing? Considerable controversy surrounds the proper interpretation of these syntheses, particularly in the area of cognitive abilities (Eagly, 1995). There is a polarity between biologically and socially oriented researchers. "Particularly now, when "political correctness" has become a hot button, this area of research is something of a political minefield" (Holden, 1991). For example, those at the biological end of the spectrum assert that gender differences have as much to do with the biology of the brain as the way we are raised (Gorman, 1992). Other more socially-oriented researchers (e.g., Feingold, 1988; Hyde, 1981, 1990, 1994) argue that differences in cognitive abilities are negligible in magnitude and decrease over time. For example, using proportion of standard deviation measures where positive values mean women scored higher and negative values mean men score higher, differences in scientific skill among 17-year olds went from −.50 in 1976 to −.28 in

1985; differences in math skills have gone from about −.2 in 1978 to about −.18 in 1986; differences in verbal skills declined from .23 prior to 1973 to .11 in 1988; and gender differences in spatial ability have declined from −.30 before 1974 to −.13 in 1986 (Adler, 1989). Others (e.g., Halpern, 1989, 1992), on the other hand, maintain that the available findings show important cognitive gender differences. Halpern (1989) points out that hundreds of studies have found consistent gender differences on subtests in three cognitive area: female superiority in verbal abilities and male superiority in visual-spatial and mathematical abilities.

According to Halpern (1989), there are three reasons for the unwarranted conclusion that the gender differences for verbal and visual-spatial abilities are shrinking: (a) Reliance on samples of high school students to address the issue of cognitive gender differences has resulted in an underestimation of the female superiority in verbal abilities; (b) the use of high school students has created trends in the verbal and spatial tests that are artifacts caused by the changing nature of the high school population; and (c) the questions asked on these tests do not assess the areas in which the greatest gender differences are found.

Sex differences in central tendency, variability, and numbers of high scores have been extensively studied, but research has not always been consistent. For example, Jensen (1971) reviewed the literature on sex differences in intelligence quotient (IQ) and concluded that the standard deviation of male IQ scores was about 20% larger than that of females. These biases may be relatively small but have effects that are not negligible when comparing real sex differences. Because most studies have not used representative samples of national populations, therefore compounding biases due to selection and sampling, Hedges and Nowell (1995) recently conducted an analysis of mental test scores from six major studies that used national probability samples. Their study provided evidence that, although average sex differences have been generally small and stable over time, the test scores of males consistently have larger variance, as seen in Table 2. The difference is typically 5% to 20%. Moreover, there is little indication that variance ratios change over time. Except in tests of reading comprehension, perceptual speed, and associative memory, males also typically outnumber females substantially among high-scoring individuals. In mathematics, science, and social studies, more males than females were in the upper tails of the distribution (ratios of 1.3 to 3.4 in the top 10%) and more females were in the lower tails. The differences favoring males were more profound in the vocational aptitudes scales, with 8 to 10 times as many males as females scoring in the top 10%. The large sex differences in writing ability suggested by one of the data sets, the National Assessment of Educational Progress (NAEP), are alarming, particularly because the differences were found on assessments that used actual writing samples. The data show that males, on average, have a decided disadvantage in the

Table 2.—Average Difference In Means, Variance, And Numbers of Extreme Scores (adapted from Hedges & Nowell, 1995)

			Tail Region		
Subject	d	VR	<10%	>90%	>95%
Reading Comprehension	−.09	1.12	1.44	.90	.93
Vocabulary	.06	1.05	.98	1.10	1.14
Mathematics	.16	1.15	1.05	1.62	1.94
Perceptual Speed	−.28	1.06	1.66	.73	.76
Science	.32	1.25	.79	2.57	5.57
Social Studies	.18	1.20	1.06	1.94	2.62
Nonverbal Reasoning	−.09	1.09	1.25	.92	.84
Associative Memory	−.25	.99	1.41	.60	.56
Spatial Ability	.19	1.27	.81	1.88	2.36
Mechanical Reasoning	.76	1.60	.48	8.25	10.95
Electronic Information	.97	2.14	.53	11.60	9.90
Auto & Shop Information	1.02	2.34	.44	66.30	464.00

Note: d = effect size in standard deviation units; VR = variance ratio, male to female.

performance of this basic skill. Although these results do not shed light on the origins of sex differences in either mean or variability, they do have significant implications for women in science. Hedges and Nowell note that small mean differences combined with modest differences in variance can have a surprisingly large effect on those that excel. "The achievement of fair representation of women in science will be much more difficult if there are only one-half to one-seventh as many women as men who excel in the relevant abilities" (p. 45).

Although we have seen that some researchers attribute male superiority in some skills to greater score variability among males, there are some interesting biological explanations that bear some relationship to behavior. For example, Doreen Kimura, a researcher at the University of Western Ontario, suggests that women with high testosterone levels and men with low testosterone levels have higher spatial and mathematical abilities than low testosterone women and high testosterone men. Relatedly, women respond more like men in tests during low-estrogen phases of their menstrual cycle (Hampson & Kimura, 1988). A similar enhancement of motor skill has been found during the estrogen phase of hormone-replacement therapy (Kimura, 1989). Kimura studied the way men and women think and found that men take more direct routes and make fewer errors, while women rely more on landmarks and make more errors (Kimura, 1992). Evolutionary psychologists believe that men excel at thinking in three dimensions due to ancient evolutionary pressures related to hunting, which requires orienting oneself while pursuing prey. Such prehistoric pursuits may have conferred a comparable advantage on women. In experiments in mock offices, women proved 70% better than men at remembering the location of items found on a desktop—perhaps

reflecting evolutionary pressure on generations of women who foraged for their food (Gorman, 1992).

These differences often show up during the acquisition of certain tasks (e.g., men tend to acquire some spatial, quantitative, and psychomotor skills easier than women). Such differences have prompted instructional researchers (e.g., Regian & Shute, 1994) to observe a simple instructional intervention that significantly reduces (and in some cases, eliminates) post-training gender differences in a psychomotor/spatial task. Using the acquisition of a high-performance skill on a video game-like task to study the relative contribution of nature (differences in testosterone level) versus nurture (experiential differences), they found that, if female subjects were required to participate in discussion groups with males in which they talked about video game strategies, tactics, and motor skills, their performance dramatically increased. Shute and her colleagues at Armstrong Labs have just completed a comprehensive set of studies in which they explicitly tested the relative contribution of instructional intervention and testosterone level across a range of tasks varying in the importance of spatial skills. Regian and Shute (1994) observe that "The results from this type of research may have far-reaching ramifications. In cases where experiential deficits account for gender differences in performance, the availability of appropriate instructional interventions may double the potential pool of qualified trainees by allowing gender-blind assignment of recruits to job skill categories. In cases where physiological differences account for gender differences in performance, it may be better to select trainees based on these physiological factors rather than gender" (p. 5). We will explore later other studies that address whether equating for practice can erase gender differences in the acquisition of a skill.

Visual-Spatial Abilities

The largest and most consistent differences between male and female performance seem to be found on selected tests of visual-spatial abilities. Based on a meta-analytic analysis of visual-spatial abilities, Linn and Petersen (1985; 1986) concluded that reliable gender differences are found at around 7 or 8 years of age (probably as early as they can be measured), increase at age 18, and continue throughout the life span. However, it was determined that there are three distinct categories of spatial tests: spatial perception, mental rotation and spatial visualization. Tests of spatial perception, defined as the ability to determine spatial relations despite distracting information, produced a mean effect size of 0.44. Tests of mental rotation, defined as the ability to rotate quickly and accurately two- or three-dimensional figures, in imagination, showed a mean effect size of 0.73.

Spatial visualization, defined as the ability to manipulate complex spatial information when several stages are needed to produce a correct solution, yielded a mean effect size of 0.13. In addition, these size effects increase with age (Voyer, Voyer, & Bryden, 1995).

There are several theories as to why males are superior to females in spatial abilities, most of them biological in nature, including genetic theories and brain lateralization theories. Both theories are founded on the assumption that performance on spatial tasks reflects an underlying, predetermined pattern of sex differences. However, such other factors as environmental pressures, verbal facility, or learned problem-solving strategies may also affect hemispheric preference in processing tasks. David Lohman of the University of Iowa (1987) hypothesizes that the core difference has to do with what he calls the "visual-spatial scratchpad," the mental ability to retain and manipulate spatial and numerical data that cannot be solved verbally. Several tests seem to rely on this ability. One is a speed of closure task, which involves the identification of a distorted or incomplete image. Another is a test of "horizontality," in which the subject must draw a line to show the water level in a tilted glass. Males not only perform these tasks better than females, they do them more quickly. When females get a correct answer, they seem to get it by reasoning, but men just look at it and know that's the way it is . . . it's almost as if they look at it without trying to analyze and process it (Holden, 1992).

Gender differences in visual-spatial abilities are well-documented, with males performing more accurately on tasks involving such things as block design, disembedding figures from background, and perceptual mazes (e.g., Harris, 1978; Maccoby & Jacklin, 1974; Sherman, 1978). Sherman (1978) introduced the strategy account which is opposite that of the genetic or biological theorists. According to her "bent-twig" hypothesis, girls apply verbal solutions to visual-spatial problems due to early precocity, while boys find "mentally spatial" approaches more successful. These styles are reinforced by social factors. Blough and Slavin (1987) considered the hypothesis that men and women employ different problem-solving strategies by examining studies that employ reaction time (RT). For example, verbal solutions may be more time consuming than mentally spatial approaches. Mental rotation, requiring kinetic mental imagery and included in many tests of spatial ability, is closely related to RT. In previous studies of gender differences in mental rotation (Kail, Carter, & Pellegrino, 1979; Tapley & Bryden, 1977), females seemed to employ an analytic, feature by feature rotation strategy, whereas males applied a holistic approach. Examining gender differences in reaction time and accuracy on four visual tasks, Blough and Slavin found that women were more accurate but slower on a standard visual choice task, which demands minimal use of mental imagery. They had higher reaction times on the

two tasks which demand a great deal of mental imagery. These gender differences interacted significantly with the degree of rotation and dissimilarity of the test form, suggesting the presence of gender differences in visual-spatial strategies. Women's longer RTs overall conform to the verbal pattern identified by Cooper (1976; 1982) as ''analytic'', while the spatial pattern adopted by men conforms to a ''holistic'' type of strategy. Their longer RTs also support the notion that women prefer accuracy to speed when confronted with mental rotation tasks where there are speed-accuracy tradeoffs (e.g., Tapley & Bryden, 1977; Kail et al., 1979; Lohman, 1986). Bryden, George, and Inch (1990) confirmed this finding, but found that, although women take longer to manipulate three-dimensional objects in space, they employ the same general strategy as men.

The suggestion that individuals may develop a learned strategy for problem-solving refutes the biological notion. For example, several studies (Connor, Schackman, & Serbin, 1978; Goldstein & Chance, 1965; Johnson, 1976) demonstrated that sex differences in performance on one spatial measure, the Embedded Figures Test (EFT), could be eradicated through practice and through the training of females. Tobin (1982) found that sex differences could be eradicated by a single, brief practice session alone for adolescents between the ages of 13 and 16. This finding calls into question the validity of an interpretation based on the hormonal differences because biological explanations would predict that a sex difference in adolescence would be resistant to change.

Experimental Evidence for Gender Differences in Skill Acquisition

We now describe several somewhat similar experiments that examined gender differences in the skill acquisition of complex tasks. The purpose is to determine what influence basic skills have on performance and whether pre-experimental levels of performance for males and females will be modified by practice or specific training interventions.

A series of studies by McCloy and Koonce at the Air Force Academy (e.g., McCloy & Koonce, 1981) was designed to determine just how different males and females are in cognitive style and psychomotor abilities, whether one could expect a gender difference in the acquisition of skills, and whether or not prediction equations developed to optimize the selection of males for a skill would be adequate for the selection of females for the same task. They used a battery of cognitive measures, consisting of tests of perceptual speed, visual memory, spatial orientation, and spatial scanning from the Ekstrom, French, Harman, and Derman (1976) kit of factor-referenced cognitive tests, the Embedded Figures Test (field independence {Witkin, Oltman, Rasking, and Kark, 1971}), and three psychomotor tests.

Table 3.—McCloy and Koonce (1981) Regression Results: Sex as a Moderator Variable for Skilled Performance

Study 2		
Overall	Group	Sex Within Group
0.593		
	CON 0.652	M 0.850
		F 0.782
	COG 0.783	M 0.733
		F 0.871
	COG + MOT 0.615	M 0.394
		F 0.763

Study 3		
Overall	Group	Sex Within Group
0.488		
	CON 0.589	M 0.980
		F 0.690
	COG 0.704	M 0.825
		F 0.971
	COG + MOT 0.684	M 0.889
		F 0.805

In Study 1, 51 males and 52 female freshman cadets participated in three 50-minute sessions over a two month period. Subjects were given the cognitive and psychomotor tests in the first two sessions. In the third session each was instructed how to perform four basic flight maneuvers (climb, cruise, descent, and turn) using a desktop flight simulator. Each was given practice on the maneuvers, and then tested on his or her performance while flying these maneuvers in simulated smooth and turbulent air conditions. On all of the psychomotor tests and all of the simulator flight maneuvers in rough and smooth air, the males were significantly better than the females (*p*,0.001). Applying stepwise regression techniques to predict flight performance, one of the perceptual motor coordination tests and a perceptive speed test were the significant predictors for males, but for females the pursuit rotor and a cube comparison test were the significant predictors.

The second study was conducted a year later on the same subjects. Based on pre-test performances, they were divided into three equal groups of males and females for control (CON), cognitive training (COG), and cognitive and motor training (COG + MOT). Following training, they were then tested on their abilities to perform the four basic flight maneuvers. When multiple regression equations were applied, they became stronger as the subjects overall were broken down into their respective training conditions, and even more when divided into sex within groups.

Results, as shown in Table 3, indicate that sex is indeed a moderator variable

in the prediction of basic flight performance. Also, novices that are not very familiar with a skilled task to be performed will benefit more from both cognitive and motor training than from cognitive training alone.

These results were replicated in a third study in which the same subjects were then instructed on how to perform a chandelle, a more cognitively demanding task than the four basic maneuvers previously learned. The results were similar to those of the second study, continuing to support the idea of sex as a moderator variable. The individual regression equations by sex also had different predictor variables. Further studies by McCloy and Koonce actually ''trained out'' differences between males and females, i.e., using comparable tasks, males and females transferred their training equally from one task to another. These results seem to suggest that there are different perceptual and mental approaches to attaining success on a task for males and females.

In recent research (Kennedy, Turnage, & Lane, 1996) again studying visual-spatial cognitive predictors, we specifically examined changes in male and female performance over extended practice. This is the type of study that can shed some light on how skill acquisition curves differ between genders and whether differences increase or decrease as a function of time on task. The purpose of the study was the determination of predictive validity between multiple test batteries and complex task performance on a high performance flight simulation task. The Portable Inflight Landing Operations Trainer (PILOT) was developed (Justiz, 1993) to assist NASA Shuttle Commanders and Pilots in maintaining the highest possible level of shuttle approach and landing proficiency while on-orbit for extended periods. The system is described elsewhere (Kennedy et al., 1996). Thirty-one students (19 male and 12 female) participated in the study. Each participant claimed to be experienced and familiar with computers and had played video games to some degree.

The series of tests included video based tracking scenarios, postural stability tests, cognitive performance tests, visual acuity/reflex tests, and the PILOT performance task, all of which were microcomputer-based except for the postural stability test. Each participant completed seven sessions within approximately a three-week period. The Shuttle Landing task was given for eight trials per session, with Sessions 1–6 presented under normal conditions and Session 7 presented as a wind condition. All other tests were given once per session with the exception of postural stability and dark focus which were administered before and after each set of shuttle trials.

We found some consistent gender differences in most of the test scores. For contrast sensitivity, a test of static visual acuity, there were small but consistent gender differences at all frequencies, with means for females slightly below those of the males. Differences ranged from 1.0 to 1.5 standard errors at all frequencies

other than 1.5 (no differences) and 18 cps (p,0.05). For the temporal factors battery, which consists of seven tests of dynamic visual acuity, gender differences were present, but modest and inconsistent. Males had a slight advantage on most variables in early trials, with differences decreasing or disappearing in later sessions. None of the differences was statistically significant taken across all sessions.

For the cognitive tests, there were distinct gender effects, with means for females below those for males for nearly every session on each variable ($p <$ 0.05 or greater for all variables except Code Substitution and Tapping). This result we think is in large part due to two factors. First, there were four males in the present study who seemed to be unusually skilled on all tests, not just the DELTA battery. Second, there were six subjects who evidently had consistent difficulties with most of the tests, DELTA and others. They demonstrated ''quitting'' behavior at one or more points during performance, perhaps due to lack of motivation or boredom with repeated testing. All six were females; and three were excluded from analyses. These motivational problems, as well as the gender differences, are consistent with results reported by Ackerman, Kanfer, and Goff (1995) that we will turn to next.

There were also strong gender differences on some of the video games. Differences were significant on Air Combat Maneuver (ACM) Score ($p < 0.002$), Missed gates ($p < 0.001$), and Hill Time ($p < 0.002$). There were also Gender X Practice interactions for ACM Score ($p < 0.0001$) and Hill Time ($p < 0.001$), suggesting *different* shapes in the learning curves (very large initial differences, decreasing with practice). A few females had considerable difficulty with the tasks in early practice, and these negative experiences may have been reinforced by the need to continue task performance over a large number of additional trials to complete the experiment. Again, these problems of decreasing expectations and their impact on performance are similar to those reported by Ackerman, Kanfer, and Goff (1995). It is interesting to note that, for the Air Combat Maneuver video game, there was a significant difference in the total number of shots fired by females and males. Males shot as fast as possible, suggesting they were using a speed strategy, while females who fire less rapidly seem to be employing an accuracy strategy.

Finally, with regard to the shuttle landing scores, seen in Figure 1 as JNM, there were again large and consistent gender differences across the entire study. These differences were highly significant ($p < 0.0001$) in a repeated measures ANOVA. The expected decrement in performance due to wind effects was present only for females; males actually tended to show a slight increase across those blocks. This means that gender differences are unlikely to disappear without considerable extended practice. When log regression curves were fitted to the data,

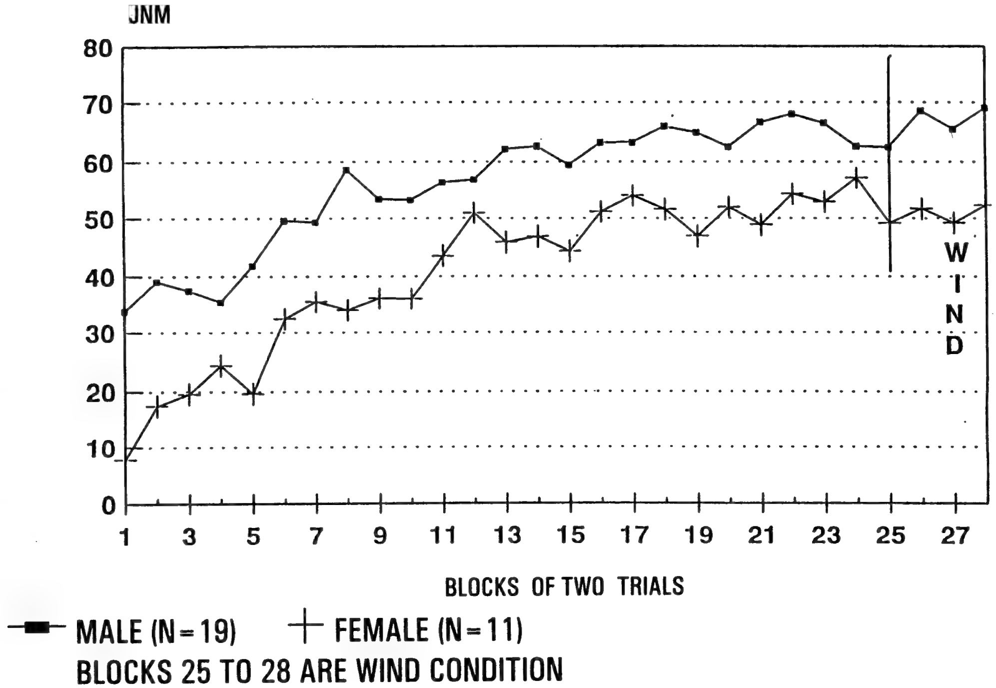

Fig. 1. JNM by block by gender

they showed that, while the curves were converging, they remained considerably discrepant even after the several hours of practice over the 56 trials.

Although not a skill acquisition study per se, a recently published study by Tirre and Raouf (1994) from the Armstrong Labs at Brooks AFB offers some insight into the nature of gender differences in perceptual-motor performance. Tirre and Raouf asked "What roles do general cognitive ability and video game experience have in determining perceptual-motor performance?" Perceptual-motor abilities include coordinated movements of two or more limbs, precisely controlled movements in response to dynamic stimuli, speeded movements, and steadiness of hand-and arm movements. They are measured by the same indices of perceptual-matching/multilimb coordination that were used in the McCloy and Koonce (1981) study previously described. Many tests that measure these abilities include a substantial visual perception component. Based on the findings of Law, Pellegrino, and Hunt (1993), Tirre and Raouf predicted that gender differences would be independent of experience, using three perceptual-motor video game tasks. Law et al. had found that dynamic spatial asks (e.g., predicting which of two moving objects will reach a point first) reflected gender differences even after video game experience was controlled. Three perceptual-motor components and one spatial rotation component were used as dependent variables. Gender

differences favoring males were significant on two of the four components—a perceptual matching with multilimb coordination factor and a speed of hit factor. Video game experience was also correlated with performance on all dependent variables. However, the gender X video game interaction was only significant for one component, that of perceptual-matching with multilimb coordination. The authors suggested that further investigation be devoted to the type of video game experience women have had before concluding that video game experience benefits only men. For example, they say "it is possible that women in our sample who reported more video game experience might have engaged in this activity mainly to please their boyfriends or might have been passive observers of their boyfriends playing the games." (p.A53). We suggest, on the other hand, that the noncomparability with previous findings of Law et al. could be a reflection of noncomparability between tasks—Law and colleagues used a spatial reasoning task while Tirre and Raouf used a perceptual-motor performance task.

Ackerman and Kanfer (e.g., Ackerman, 1992) are the only researchers that we know of other than ourselves who are currently examining gender differences in skill acquisition over time. Using a terminal radar approach controller (TRACON) simulation common to air traffic controllers, they have validated and extended Ackerman's (1988) theory of cognitive ability determinants of individual differences in skill acquisition. That theory concerns ability-performance relationships as a function of three task characteristics: (a) consistence of information processing, (b) task complexity, and (c) degree of task practice. Consistent with earlier findings (e.g., Maccoby & Jacklin, 1974), Ackerman (1992) found that men, on average, tended to perform better than women on spatial ability tests; women, on average, tended to perform better on the perceptual speed tests. However, at the composite level, only the perceptual speed measure indicated a significant difference in means, with higher scores by women. A general TRACON task performance variable showed men performing better overall than women ($p < 0.01$), and a significant interaction between sex and practice ($p < 0.01$), in addition to the main effect of practice. The interaction is indicated as a divergence in performance between the two groups with increasing practice on TRACON.

A more precise view of gender differences emerged in examination of arrivals, departures, and overflights accepted. Arrivals and departures showed main effects of sex ($p < 0.01$) and an interaction effect between sex and practice ($p < 0.01$), with men having a greater advantage later in practice. Overflights did not indicate main effects for sex or an interaction effect, perhaps due to the fact that overflights seem to have a diminished demand for spatial abilities.

Ackerman suggested that the sex differences found in this experiment pose a "vexing problem from both selection and training perspectives." Although

women scored higher on perceptual speed composites than men, their performance on the task component most dependent on perceptual speed ability was only equivalent, and not superior, to that of men. For the task component that featured arrivals, which would be most dependent on spatial abilities, women performed significantly more poorly on average throughout the task. In addition, there seemed to be a cumulative performance deficit, with increasing sex-related differences with increasing task practice. Ackerman observed that many previous studies regarding the effect of experience and practice on sex differences in spatial ability have used tasks that overwhelmingly provide for controlled consistent information processing. In these tasks, overall individual differences are attenuated simply because the distribution of performance becomes leptokurtic. However, consistent with his theory of ability determinants of skill acquisition, he observed that the current investigation focused on a task that required a substantial amount of inconsistent information processing and, as such, precluded the attentuation of individual differences in performance. Ackerman suggested that other sources, perhaps *noncognitive* sex differences such as learning versus performance orientation (e.g., Dweck, 1986) may be responsible for such effects.

Using a similar experimental paradigm, Ackerman, Kanfer, and Goff (1995) recently followed up on the suggestion that noncognitive determinants are likely operative in complex skill acquisition. The researchers examined a wide array of predictors, including ability factors, personality factors, vocational interests, self-estimates of ability, self-concept, motivational skills, and task-specific self-efficacy. Ninety-three trainees were studied over the course of 15 hours (2 weeks) of skill acquisition practice on the TRACON simulation task.

Similar to previous studies (e.g., Ackerman, 1992), Figure 2 shows that there was a significant main effect for trainee gender on overall performance ($p < 0.01$), and an interaction between trainee gender and sessions of practice ($p < 0.01$). As before, the interaction is shown as a divergence in performance between the two groups with increasing practice on TRACON. In agreement with previous findings, as well, analyses of arrivals and overflights showed higher correlations between arrival performance and math-spatial abilities than for overflights, and the differences between gender groups showed greater advantages to men over women in handling arrivals. For arrivals there were significant main and interaction effects ($p < 0.01$), but overflights showed a smaller gender effect and a nonsignificant interaction. Again, these results support the assertion that handling arrivals requires more complex spatial information processing than does the handling of overflights.

There were also interesting concomitant variables and consequences of practice. For example, women reported a significantly higher frequency of negative motivational thoughts over practice ($p < 0.01$), and a significant interaction of

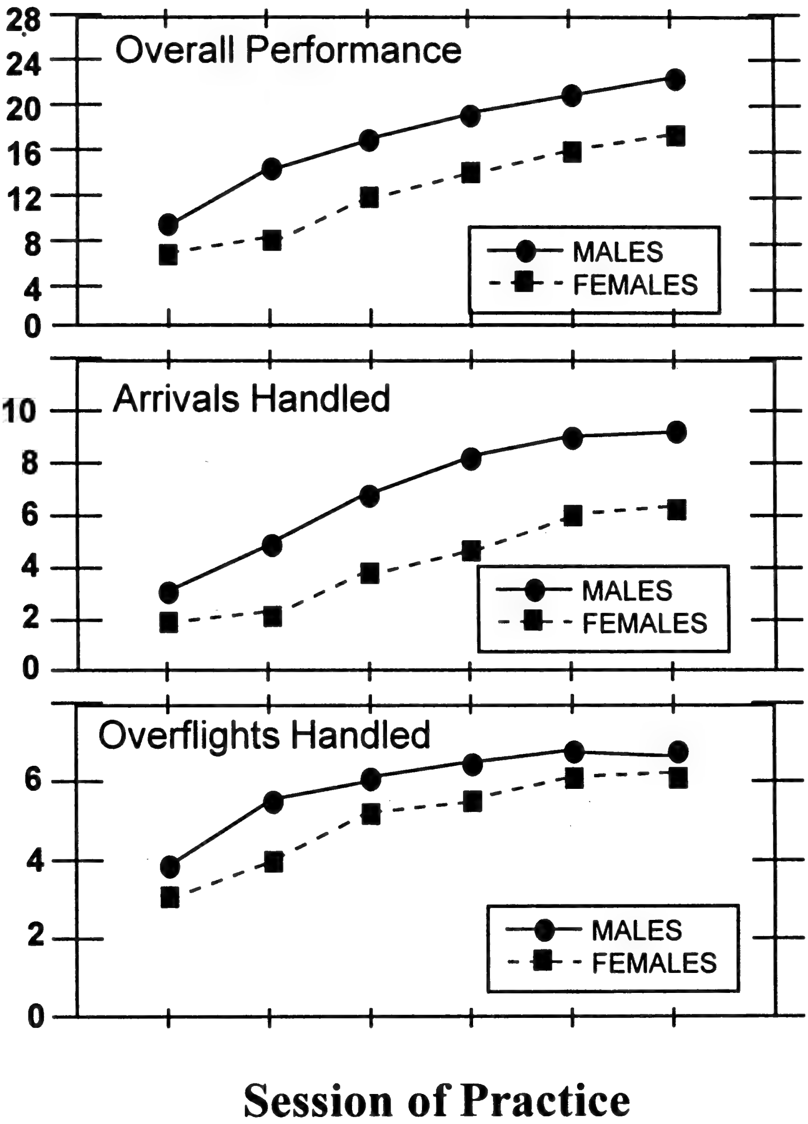

Fig. 2. Mean terminal approach controller task performance by gender over sessions of practice. From Ackerman, Kanfer, & Goff, 1995. Copyright © 1995 by the American Psychological Association. (Adapted with permission.)

Gender X Session ($p < 0.01$). This reflected a convergence of male and female reporting of negative motivation thoughts over practice. In addition, for frequency of planning thoughts, there was no main effect for gender, but significant increases in planning over the course of practice and a significant interaction of Gender X Practice. Examination of the means showed that the interaction was the result of women reporting less planning than men early in practice but more planning later

in task practice. In terms of self-efficacy, four measures of self-efficacy for TRACON performance were taken prior to each TRACON session. For each of the four self-efficacy measures, there were substantial and significant effects of gender on score (with women having lower mean self-efficacy scores for all aspects of the TRACON task), and sessions of practice (with self-efficacy dropping from Session 1 to Session 2 and then rising after Session 2). Significant Gender X Practice interactions were found, SE(Handled) and SE (Arrivals), with a divergence of scores for men and women. In hierarchical multiple regression analyses, where gender was added after all the other predictor variables had been taken into account, gender accounted for a significant amount of variance in the arrival component of task performance but accounted for virtually no incremental variance in the overflight component.

At this point, it is not clear whether the differences in performance between men and women be attributed to sex differences in higher order spatial abilities (such as visualization) or to differences in strategies for task engagement and learning (although see Lohman, 1986, 1987, for a discussion of both sex differences in spatial information processing and on the structure of spatial abilities, respectively, cited in Ackerman, 1992).

Implications

These cumulative results demonstrating that task performance that depends particularly on spatial abilities diverges with practice for males and females has distinctly negative implications for those who aspire to see women more equally represented in scientific and technological disciplines. Newsweek (Kantrowitz, 1994) not too long ago ran a cover story titled "Men, Women, & Computers." The article started by citing the story of a long-time "Star-Trek" devotee who happened to be a woman. After repeated tries to be part of a Trekkie discussion group on the Internet, she was chased off the net by rabid hounds, or "fire Phasers," the male Trekkies who flooded her e-mail with nasty messages. So she retreated into her own galaxy by starting the all-female Starfleet Ladies Auxiliary and Embroidery/Baking Society. The article's author observed, "From the Internet to Silicon Valley to the PC in the family room, men and women often seem to be like two chips that pass in the night" (p.50). In general, computer culture is created, defined and controlled by men; women often feel as welcome as a system crash. Anecdotal evidence seems to support the notion that men tend to be seduced by the technology; they get into the faster-race car syndrome, bragging about the speed of their microprocessors. Women, on the other hand, are much more practical and much more interested in the machine's utility; they just want it to do the job.

Although boys and girls are equally interested in computers until about the fifth grade, at that point boys' use rises significantly and girls' use drops (Kantrowitz, 1994). Many experts think that the increasingly violent nature of video games—particularly against women—is playing a big role in creating a "gender gap" in computer technology professions, where men vastly outnumber women. Examples of the gender gap are evident around the country: Nationwide, less than 28 percent of all computer science degrees go to women. Since the 1980s, the number of women entering computer professions has dropped by 50 percent. The number of women receiving bachelor's degrees in computer sciences at the University of Central Florida declined almost 70 percent from 1986 to 1995 (Burnett, 1996). Although game manufacturers are now trying to lure girls with more appealing games, it will not be an easy task. However, Sherry Turkle, a MIT professor who has studied gender differences in computer usage, thinks that gender differences could actually help women. She says "We're at a cultural turning point; there's an opportunity to remake the culture around the machine." Practicality is now as valued as invention (Kantrowitz, 1994, p. 55).

These studies on gender differences, particularly in the realm of visual-spatial abilities, need much further research. Several explanations have been offered to account for the prevalence of sex differences in spatial abilities. For example, variables such as choice of strategy (Bryden, 1980), rate of maturation (Sanders & Soares, 1986; Waber, 1976), cerebral lateralization (Bryden, 1979; Levy, 1971), genetic complement (McGee, 1982), sex hormones (Imperatio-McGinley, Pichardo, Gautier, Voyer, & Bryden, 1991); McGee, 1979), differential experience and socialization (Baenninger & Newcombe, 1989), and sex role identification (Nash, 1975; Signorella & Jamison, 1986) have all been proposed as possible causes. As Voyer et al. have noted, because some tests consistently show reliable and significant sex differences, it would seem important to understand the processes underlying these tasks, including brain structure, hormonal and experiential factors. It has also been shown that method of administration also affects performance and may be responsible for the decreasing effect sizes observed in recent years. This suggests that a detailed examination of the way in which these tests are scored and administered may lead to valuable information (Voyer et al., 1995).

To these potential explanations for gender differences, we would like to add a few other observations and suggestions. The first observation has to do with the choice of tasks in the skill acquisition studies that we have reviewed. In all instances, the criterion task is a male-oriented task that features ability prerequisites on which males are known to excel—where spatial abilities, psychomotor behaviors, and quick reaction times equate to superior results. In our shuttle landing study, we found that video games correlated so highly with shuttle landing

performance that game scores consistently dropped out from any prediction equations. But we have seen that video games and other perceptual-motor tasks do not interest women. Both Ackerman and we found severe motivational problems in keeping female participants focused on task performance in our studies. They have negative thoughts and generally exhibit quitting behaviors when faced with continued exposure to the task. Not surprisingly, then, their self-efficacy decreases and performance differences between the genders become more pronounced with increased exposure to the task. Would the same results occur if the task were one which was not so male-oriented? What if the task were a problem-solving task that was relatively more dependent on verbal abilities, associative memory, or perceptual speed, on which women hold a performance advantage? What if we looked at the bigger criterion picture and included tests for practical, tacit and emotional intelligence (e.g., Sternberg, Wagner, Williams, & Horwath, 1995)?

We also saw that women profit more from verbal instructions than do men in the McCloy and Koonce and the Regian and Shute studies. Could that advantage be due to females' greater verbal abilities? Likewise, they profited more from training that featured explicit motor practice. They also use different combinations of skills and abilities than men to achieve similar results. This conclusion is supported by the very different prediction equations for males and females that were found in the McCloy and Koonce studies. These observations suggest that female-oriented interventions that capitalize on female interests and skills, such as merely talking about strategies, can improve performance. In most of the studies cited here, both predictor variables and criterion variables are those where there are known male advantages, but it is highly likely that selecting female-oriented predictors would shed a different perspective on skill attainment. We know that males and females approach and solve problems differently, so let us get on with the task of determining how best to use the best of nature and nurture in both sexes to improve performance on a wide variety of activities that have universal significance in our world of work and living.

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How Body Height and Weight Affect Our Performance, Longevity, and Survival

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ABSTRACT

Human body size is evaluated in terms of its impact on the earth and the future of mankind. Key aspects of human existence are quantitatively evaluated, including performance, longevity, resource consumption, pollution, and economics. Various U.S. and international studies relating height, weight, and mortality are examined. Evidence is presented to show that a population of smaller size people would not negatively impact human performance and would ameliorate food, water, health, and environmental problems. A nutritional strategy is presented for conserving resources and producing healthy and active people into old age.

Performance and survival are strongly affected by the average size of an animal and its environment. Over 10000 years ago, North and South America saw the extinction of over 135 species of animals. Virtually all of these species were over 45 kg. The Dinosaurs also disappeared 65 million years ago but smaller animals, such as turtles, crocodiles, snakes, and lizards survived to the present time. It is obvious that larger animals, such as humans, need more resources to survive and flourish. Each human being consumes enormous amounts of food, water, and other resources. Over a lifetime, the average American requires 237 million liters of water, 4545 kg of meat, 4091 kg of grains, 12727 kg of milk and cream, and 89040 liters of gasoline. When these resources are multiplied by 6 billion people, the scope of the problem is awesome. Yet, this area of study has been neglected by virtually the entire scientific community. However, there have been several scientists who have recognized the importance of human size on our day-to-day lives and long-term survival. These have included Dr. Benjamin H. Alexander, Dr. Ashley Montagu, Dr. John Yudkin, Dr. Lowell H. Storms, Dr.

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Harold Elrick, and Dr. Dennis D. Miller. Engineering professors Hansen and Holley (1967) also recognized the importance of size many years ago when they pointed out the impact of smaller human size on buildings, power sources, transportation facilities, and food needs.

It is the purpose of this paper to explore and quantify the ramifications of increasing human size on our performance, longevity, environment, and future. However, a brief background review of some key areas will be given first.

Secular Growth

''Secular growth'' refers to the progressive increase in the size of the average person over the last 200 years. People in many countries experienced an increase in stature after the initiation of the industrial revolution. This increase in Europe has averaged about 2.54 cm per generation. However, growth has been uneven over this period and some countries have lagged behind others. For example, the Portuguese, Spanish, and Italians are a few inches shorter than the taller Northerners, such as the Dutch and Norwegians. In 1760, the average Norwegian military recruit was under 1.6 m. Today, he averages 1.8 m. More recently, the Japanese and Chinese have had a remarkable growth rate of 2.54 cm per decade—a much more rapid rate than Europeans have experienced. Since the end of WW II, the Japanese have grown 7.6 to 12.7 cm.

Along with increasing height we have seen increases in weight. The average American male during WW I was about 64 kg, during WW II 68 kg, and now he exceeds 82 kg. Women have kept pace with men but they have generally averaged 8 to 13 cm shorter. Their body weights have also been 15 to 20% less than those of men. Overall proportions have remained fairly constant although there have been some specific variations from symmetry in body structure (Kroemer, 1990). American and Japanese studies have shown that the overall body weight has increased as the cube of height increase for different generations. From one generation to the other, weight has increased at a rate of 1 to 2 kg per centimeter of height.

Most scientists believe that this growth process cannot continue indefinitely. While we are still seeing increasing stature among the average American, the rate of height growth among the upper middle class seems to be approaching a plateau. However, scientists reported that growth had topped out over 30 years ago. This has not yet occurred. With the advent of new growth promoting drugs, we could see additional growth of our youth to satisfy what appears to be an ideal goal of 1.83 m or more for men. (The average American is continuing to put on weight at a rapid rate with no end in sight due to excess energy intake and lack of exercise, and about 1 million of our youth are taking steroids to build bigger bodies.)

Most experts in this area attribute secular growth to improved nutrition (Kunitz, 1987), sanitation, medical care, and standard of living. The Japanese growth spurt began following WW II with increasing consumption of red meat, milk, eggs, and other energy-dense foods. We also know that we can control the growth of animals through nutritional restriction, especially protein and joules.

In general, most scientists have assumed that this growth is desirable and reflects better health. However, this assumption has many pitfalls and requires a more rigorous analysis. The following sections will describe some analyses and research findings that indicate some dangers in feeding our children for maximum growth and development. Before presenting these findings, a brief overview of the concept of geometric similarity will be presented so that changes in body characteristics with increasing stature will be readily understood.

Increasing Height and Geometric Similarity

Scientists who study animals are familiar with the disproportionate changes in surface area and volume that occur when length increases. For geometrically similar animals, this means that as an animal increases in length, its surface area and volume increase at a more rapid pace. Thus, surface area increases as the square of the increase in length, and body volume and mass increase as the cube of the increase in length. Consequently, if the length of an animal is doubled, its surface area increases by 4 times and its volume by 8 times (R. Alexander, 1989). The same is true for human beings.

The consequences of these changes in body characteristics have been described by various scientists, including the exercise physiologists, Astrand and Rodahl (1986). Some of their key findings in relation to humans are summarized next. Specific percentage changes are included to illustrate the principles involved. These percentage changes are based on comparing two people of the same body type or proportions but differing in height by 20%. A 1.83 m person weighing 86.4 kg is compared to a 1.52 m person weighing 50 kg [$(1.829 \text{ m}/1.524 \text{ m})^3 \times 50 \text{ kg} = 86.4 \text{ kg}$]. Thus, body height is the independent variable to which all other body characteristics are related.

Body Dimensions: A 20% increase in height or length (L) results in a 20% increase in body width and depth when geometric similarity is maintained.

Body Area. Body area is proportional to the square of the increase in height; e.g. $(1.83/1.52)^2 = 1.44$. The 1.83 m person will have 44% more surface area than the 1.52 m person or 2.06 m^2 vs 1.43 m^2.

Body Volume. Body volume is proportional to the cube of the increase in body height. The 1.83 m person will have a 1.73 times or 73% greater volume of 86.4 liters vs 50 liters for the 1.52 m person.

Body Weight. Body weight is proportional to the cube of the increase in body

height. The 1.83 m person will weigh 86.4 kg compared to 50 kg for the 1.52 m person. Thus, the taller person will weigh 73% more than the shorter person. (Body density is about that of fresh water and is about the same for tall and short people of the same body type.)

Strength. Strength increases as a function of muscle cross section. Since a cross section is an area, maximum body strength increases as the square of the increase in height, or by 44% for the 1.83 m person. The maximum strength of tendons, ligaments, and bones also increase by 44% (or 1.44 times) with an increase in height of 20%.

Strength to Body Weight. Since body weight increases at a faster rate than muscle strength, the 1.83 m person will have a strength-to-weight ratio of only .83 (1.44/1.73 = .83). Thus, the shorter person will be 20% stronger in terms of lifting his or her own body, as in chin-ups or climbing up a rope.

Acceleration. Acceleration is equal to force divided by mass. Since muscle force increases at a slower rate than body mass, the 1.83 m person will have a 17% lower ability to accelerate his or her body compared to the 1.52 m person. (acceleration = force/mass = $1.44/1.73 \times 100 = 83\%$; thus, $100\% - 83\% = 17\%$ less.)

Endurance. For short-term anaerobic activities, the 1.83 m person would be able to produce energy in proportion to his or her weight. However, for aerobic activities, the 1.83 m person's 44% smaller lung surface area in proportion to body weight will provide a lesser rate of oxygen intake and carbon dioxide outtake. Similarly maximum cardiac output (l/min) and power output (kj/min) of the taller person would be 44% greater for a 73% increase in weight or 17% less on a kilogram-for-kilogram basis.

Brain size. The larger person's brain would in theory increase by 73%. However, studies (Pilbeam & Gould, 1974) indicate it increases at a rate proportional to $M^{.67}$ instead of M^1 (M = body mass). The relationship holds for animals ranging widely in body size. (Women have 10% smaller brains but weigh 15 to 20% less than men.)

Metabolic rate. The taller person's resting metabolic rate (RMR) will be lower on a kg-for-kg basis than that of the shorter person because of the smaller loss of heat energy from the smaller surface area in proportion to body mass; e.g., surface area would be 44% larger for a 73% larger body mass. Empirical data show that the total body RMR increases at a lower rate than increases in body mass ($RMR \propto M^{.74}$).

There are many other physical characteristics that change disproportionately with increasing height but a full discussion of these would require a separate paper. Further information on how the body changes with increasing height or

length can be found in The Truth About Your Height (Samaras, 1994), Astrand & Rodahl (1986), Haldane (Newman, 1956), and Wentworth (Newman, 1956).

The focus of this report is on measurable quantities related to human size, performance, health, and survival. However, psychosocial issues need a brief discussion because of their strong influence on how we perceive larger stature and body size. Most societies tend to equate taller stature with higher status and power. Studies reported by Samaras (1994) have shown that taller people receive more pay for the same work and are favored by employers during hiring and promotions. John Kenneth Galbraith (2.03 m) observed that height bias was one of the "most blatant and forgiven prejudices" our society has (Keyes, 1980). Other researchers have found that most people, especially men, wish they were taller, and many men feel that they are not as big as they would like to be. Virtually all of us are imprinted with this bias at an early age, and it makes it difficult to be receptive to the possibility of smaller human size. Although it took hundreds of years to convince people that the earth revolved about the sun, modern communications can accelerate our understanding of new and unusual ideas, such as described in this paper.

Methods and Materials

Material on how increasing height affects various body characteristics was obtained from a literature review, using sources involving human physiology, human engineering, and biomechanics. Other material on mortality was obtained from sources, such as scientific journals, textbooks, the World Health Organization, National Center for Health Statistics, and the California Department of Health.

Longevity data were obtained from various sources. Since very little formal research data were available relating body height and longevity, a variety of sources were used, such as San Diego Veterans Administration Medical Center, The Baseball Encyclopedia, and biographical data. The Pearson product-moment correlation coefficient was used to determine the degree of correlation between height, weight, and longevity.

The basic approach for evaluating the impact of increasing body size on the quality of life and future human survival was based on configuration management principles (Samaras, 1988). A key aspect of configuration management involves assessing the ramifications of changes in the design of a product (human for this paper) from a multifaceted perspective. Thus, proposed changes are evaluated in terms of their impact on performance, durability, maintainability, cost, survivability, and safety.

Results

The following material covers key areas related to the average size of human beings—performance, mortality, longevity, animal research, nutrition, and survival. Each is critical in determining whether smaller human size would provide mankind with a better chance of long-term survival on this planet.

Performance

Size does not appear to affect human performance in most areas of human activities. Both large and small people have demonstrated great abilities in science, the arts, technology, and leadership. It is certainly true that people in the most highly industrialized nations are taller and bigger than most of the people in less developed countries. Many executives are taller than their subordinates and tall athletes excel in basketball, football, baseball, and heavyweight boxing. However, in all these areas, shorter and smaller people have also demonstrated great capability throughout human history in spite of cultural biases favoring tall people. Since the achievements of tall people are widely known and accepted, the following discussion will focus mainly on shorter or smaller people.

History is replete with great civilizations made up of fairly small people. The ancient Greek males averaged about 1.63 m. Yet, they were great scientists, athletes, warriors, and artists. The Romans were only a few centimeters taller than the Greeks and also produced a civilization of impressive proportions. The outstanding contributions to mankind of the ancient Egyptians, East Indians, and Chinese were also made primarily by small people. The Maya, Aztecs, and Incas averaged about 1.6 m and displayed great scientific, artistic, architectural, and organizational achievements.

More recently, extraordinary Japanese industrial developments were initiated and implemented by people much shorter than the Japanese youth of today. One of the leaders of Japanese industrial development was Matsushita, the father of the electronics industry. He was 1.63 m and 58 kg. Many of the Japanese industrial leaders were likewise small men by American and Western standards. Highly successful American or European businessmen or industrialists have included Ross Perot (1.68 m), Armand Hammer (1.65 m), Aristotle Onassis (1.65 m), David Murdock (1.63 m), Herbert Haft (1.52 m), and Ronald Perelman (1.73 m). Ray Kroc and Dale Carnegie were also on the short side.

A study by Walter Bowerman (1947) found that the among 1000 British men of genius, men $\leq$ 1.62 m represented over 30% of the population. My studies have also revealed that famous short or small men represented about 30% of the famous people listed in Current Biography Yearbooks (1940–1992). A sampling of famous short people includes Michelangelo (1.57 m), Joan of Arc (1.52 m),

Buckminster Fuller (1.60 m), Martin Luther King (1.70), Picasso (1.63 m), Mother Teresa (1.52 m), Mahatma Gandhi (1.60 m), Voltaire (1.60 m), Mahler (1.62 m), Stravinsky (1.54 m), and Kant (1.52 m).

In terms of physical productivity, certain work, such as sugar cane cutting, favors taller, bigger workers. Valery Venda (1993) reported that bigger men were more efficient at shoveling dirt than smaller men. However, Rene Dubos' study of Guatamalan peasants found them to be capable of much more rigorous physical work output than expected for larger North Americans (Dubos, 1980). Balke and Snow (1965) found that the small ($<$1.65 m) Tarahumara Indians of Northwestern Mexico expended over 41900 kj over a 24-hour period during kickball racing covering over 160 km. The researchers reported that this figure is considered the upper limit of human voluntary work effort. For small men, the Tarahumara also exhibited great strength. One young Indian carried a 45 kg burden for 176 km in 70 hours.

Anthropologists Edmundson and Sukhatme (1990) found the smaller people of Asia highly productive. They reported that poorer peoples on low food intake are not physiologically under productive. In fact, most researchers in the developing world have observed that workers with low-energy intakes are often as productive or more productive than workers with high intakes.

Some studies have found that shorter children score lower on IQ tests. Recently, David Sandberg (1995) reported that an on-going study in Britain found that much of below par performance of short children could be traced to poorer socioeconomic backgrounds. In addition, anthropologists have found that smaller brain size is not an indicator of lower intellectual performance. Stephen Jay Gould (1981) found that brain size has no relation to intelligence. Also women have smaller brains (as would be expected due to their smaller bodies) but are not any less intelligent than men. Walford (1980) did not find a decline in mental acuity among smaller animals subjected to dietary restrictions.

While the most popular sports, such as football and basketball, favor tall men and women, short people have demonstrated great achievements in other sports. Sports scientist and physician Robert Cantu (1984) has pointed out that shorter size is an advantage in gymnastics, long distance running, diving, skiing, figure skating, and ballet dancing. The reasons for this are the greater aerobic capacity of lungs with larger surface areas in proportion to smaller body mass, higher strength-to-weight-ratios, and smaller rotational inertia in comparison to the body's ability to produce torque to initiate or counteract rotational movements. (Rotational inertia is $\propto L^5$ while torque produced by body muscles is $\propto L^3$.)

The recent winner of the New Orleans gymnastics championships was Dominique Moceanu, a 1.32 m, 32 kg gymnast. Kim Zmeskal, at 1.4 m also demonstrated exceptional abilities in past gymnastic events. And in spite of basketball's

bias, Muggsy Bogues of the Charlotte Hornets, is the shortest man to ever play professionally. He is 1.6 m and 59 kg. Both he and 1.68 m Spud Webb, who won the National Basketball Association slap dunk championship, were better vertical jumpers than teammates who towered over them. In martial arts, Bruce Lee at 1.68 m was an outstanding champion and many of the martial artists tend to be small. A review of the heights of professional boxers also revealed that most were short or small. The November 1995 New York Men's Marathon was won by 1.6 m, 50 kg German Silva under the coldest and windiest weather experienced during the last 40 years. Tegla Loroupe, about 1.52 m tall and almost 36 kg, won the women's marathon. Both had won the same marathon the previous year. A few years ago the Olympic weightlifting champion, Suleymanoglu, at 1.52 m and 59 kg was described as the best weightlifter kilogram for kilogram. Polednak (1979) reported that the U.S.S.R. weightlifters averaged 1.67 m and 77.3 kg while Finnish champion lumberjacks averaged 1.74 m and 72.7 kg.

In warfare, short men have demonstrated high courage and ability. Examples include the ancient Greek and Roman soldiers. In recent times, the small Gurkhas of Nepal and WW II Japanese have demonstrated impressive fighting abilities. Early American Indian warriors, such as the Apache, Comanche, and Navajo, were short (Samaras, 1994). Military historian Sydney Allinson (1981) described the physical advantages of short soldiers and reported that the WW I English Bantam division was cited for valor many times and took the previously impregnable Bourlon Heights from the enemy. These small soldiers (less 1.6 m) also showed ability in hand-to-hand combat when they engaged the enemy in trenches and managed to kill 30 enemy soldiers while losing only eight of their own. During WW II, the most decorated American soldier was Audie Murphy, who was 1.65 m and about 50 kg.

Mortality and Longevity

This section will review findings on mortality, longevity, and body size. While the findings may be disturbing, it is important to realize that body size is only one factor affecting an individual's longevity. Nutrition, smoking and drinking practices, heredity, socioeconomic status, medical care, satisfaction with work, and social support probably account for 80 to 90% of one's life potential. Additionally, findings should be evaluated in relation to related studies, potential confounding factors, and animal studies. For this reason, a number of sources relating human size, death rates, and longevity are presented for a broader perspective.

The following studies refer to body mass index (BMI) as a measure of obesity. High BMI numbers indicate an overweight condition and low ones a lightweight condition. BMI's can be calculated using different formulas. The mortality studies

described in this report used W/H^2, where W = weight in kg and H = height in meters. For example, the typical American male and female have BMI's slightly over 26 kg/m^2. This is quite high compared to research findings indicating that one's BMI should be closer to 20 or 22.

Body weight and mortality. A number of studies have found that the lower one's body weight for height, the lower the mortality. For example, the Harvard Nurses' Health Study (Manson, 1995) found the thinnest women had the lowest death rates from heart disease. Over 115000 female registered nurses (30 to 55 years old at the start of the study) were tracked for 16 years. After controlling for age, smoking, menopausal status, parental history, etc., women with a BMI < 19 (kg/m^2) had the lowest incidence of mortality. Researchers also found that only a 5 kg rise in weight after the age of 18 increased risk from all causes. The minimum risk BMI of <19 is a very low body mass, and a 165 cm woman should weigh only 51.8 kg. This is lighter than most champion marathon runners (BMI ~20) who are a very thin breed to start with.

Harvard male alumni were evaluated over a 27-year period by Lee, et al. (1994) for mortality risk with increasing weight. After adjusting for smoking and other factors, the study of almost 20000 found that men who were 20% below the U.S. average weight for the same height and age had the lowest mortality. For example, a 177.8 cm male weighing 82 kg would have to reduce to 65.6 kg to reach ideal weight for height.

Hoffmans', et al. (1988) study of 78000 Dutch youth tracked these men from their 18th birthday. They found that men who had a BMI of 19 to 19.99 at the age of 18 had the lowest mortality over a 32-year period. They also found that healthy, educated men who had a BMI of 19 during their youth had the lowest death rate from all causes.

Larger body size was also implicated in a long-term study being conducted in the People's Republic of China by a team of American, British, and Chinese researchers. They found that larger body size was correlated with higher incidence of heart disease and cancer. For example, the positive correlation coefficient between height and cancer was $r = .44$ ($p < .001$) and $r = .47$ ($p < .001$) between weight and cancer. For heart disease, they found $r = .33$ ($p < .05$) for height and $r = .39$ ($p < .01$) for weight.

Polednak (1979) reported that larger bodied athletes had a slightly higher risk of dying than smaller athletes. More recently, Baron (Audible, 1994) found in a study of 6848 National Football League players that the largest players had 6 times the death rate of the smallest players. Baron found a very strong association between body size, heart disease, and death and recommended that players avoid bulking up to play football.

Samaras (1994) reported that the California Department of Health found Asians

and Hispanics had a higher life expectancy than whites. They were also shorter and lighter than whites except for Hispanic women who were .9 kg heavier than white women. On a national scale, the National Center for Health Statistics (1995) reported Asians and Hispanics had considerably lower death rates from cancer and heart disease compared to bigger whites and blacks.

A review of World Health Organization (WHO, 1992) data indicates that shorter southern Europeans have significantly lower death rates from cancer and heart disease after the age of 65—the period when most people die of cancer and heart disease. Northern countries have 7.2% to 40% excess cancer and heart disease mortality. Life expectancy for age 65 and over is 1.2 years greater (8.5% longer) for the southern countries.

Cancer mortality vs height and body weight. A number of major studies have found a correlation between body height and weight and mortality from cancer. Giovannucci, et al. (1995) studied 47723 male health professionals between 40 and 75 years old. They found that the risk for colon cancer increased with BMI. Independent of obesity, they also found that colon cancer risk was 1.76 times higher for men $\geq$1.85 m compared to those $\leq$1.73 m. This finding was previously reported in other studies and was attributed to the longer colon and its greater number of stem cells at risk for transformation into cancer cells.

Albanes and Taylor (1990) also found a relationship between adult height and weight and cancer incidence. They studied the cancer incidence of 24 nations in Asia, Europe, and North America. All sites cancer incidence was highly correlated with height among both men ($r = .54$, $p \leq .001$) and women ($r = .74$, $p \leq .0001$). Weight was also related to cancer incidence although higher correlation coefficients were found for females compared to men. Stronger positive correlations were found for height than for weight.

A large study of 570000 women in Norway found that the tallest women in all age groups had the highest breast cancer risk for both morbidity (sickness) and mortality. Overweight was also a risk factor for breast cancer mortality. However, Tretli (1989) pointed out that while there is a consistent positive relation between height and breast cancer, it is not a large one.

The National Cancer Institute found higher cancer risk to be related to taller stature. Albanes, et al. (1988) studied 12554 men and women 25–74 years old and found that for most cancer sites in men, and particularly colorectal cancer, the lowest incidence was among those in the shortest quartile of stature. Taller women were found to have a higher relative risk for breast (2.1) and colorectum cancer (1.6). The researchers attributed this higher risk to over nutrition during early life.

In a study by Swanson, et al. (1989) of 5239 women, an increasing BMI (using 1.5 instead of 2 as a power of height) was associated with increasing risk of

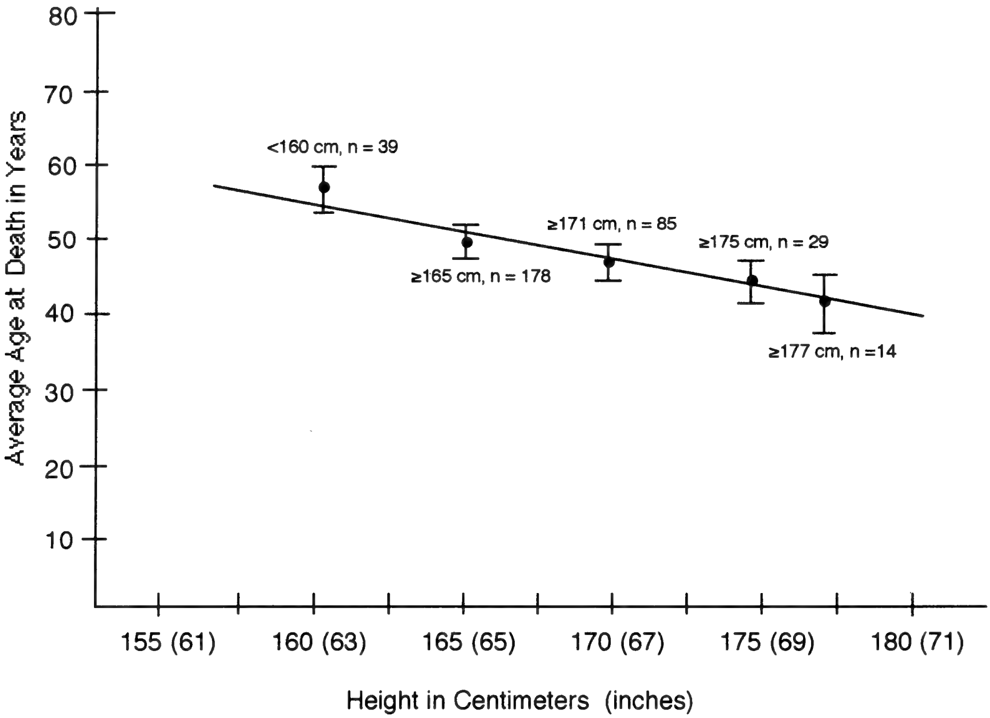
breast cancer. The population was broken up into four BMI groupings. The relative risk of breast cancer with increasing quartiles of BMI was 1.00, 1.04, 1.40, and 1.29. Independent of weight, height was also found to increase the relative risk of breast cancer with these values: 1.00, 1.07, 1.15, and 1.27.

Another study relating breast cancer and height was conducted by a Dutch epidemiologist, de Waard (1975). He found that body mass rather than obesity is an independent risk factor. The study found that the crude effect of height (including the increased weight that normally goes with it) accounted for all the risk attributed to body size. De Waard concluded that Western nutrition alters endocrine and metabolic processes and predisposes women to increased breast cancer risk.

Other studies have found a correlation between cancer risk and height. Fraumeni (1967) found that children admitted to the Children's Hospital Medical Center in Boston with osteogenic sarcoma (cancer started in bone) were significantly taller than a control group of children with non-osseous (nonbone) cancers. He pointed out that these findings are consistent with the known high risk of canine bone sarcoma among larger breeds of dogs. Lee and Kolonel (1983) found taller men had more lung cancer than shorter ones, and Hancock, et al. (1976) found taller males and females had a higher incidence of Hodgkin's disease.

Body size and longevity. In 1992, The World Health Organization published a research paper describing the negative correlation between increasing height and longevity. The study (Samaras and Storms, 1992) provided longevity data on several thousand decreased men. A group of 373 decreased veterans revealed that the shorter half of veterans averaged about 5-year longer lifetimes compared to the taller half. The correlation coefficient for height vs longevity was $r = -.23$ ($p < .001$) and for longevity and weight $r = -.20$ ($p < .001$). Evaluation of over 3200 decreased professional baseball players found a similar pattern. Absolute body weight was also found to be correlated with lower longevity. The weights studied for baseball players were during their playing years and did not account for weight changes in later years.

Miller (1990) studied data on 1679 decreased men and women provided by the Cuyahoga County Coroner's Office of Cleveland. He found a statistically significant inverse relationship between height and longevity. Miller also found that each additional centimeter in height resulted in a reduction of .47 year in average age of death. He observed that this reduction was the same as the difference between men and women based on a 12.7 cm height difference and 7-year longer life expectancy. When he compared men and women of the same height, men appeared to live as long as women. He noted, however, that his statistical analysis indicated that height contributed only 10% of the total variation in longevity. This he found to be expected because there are many other factors that affect human longevity besides height.



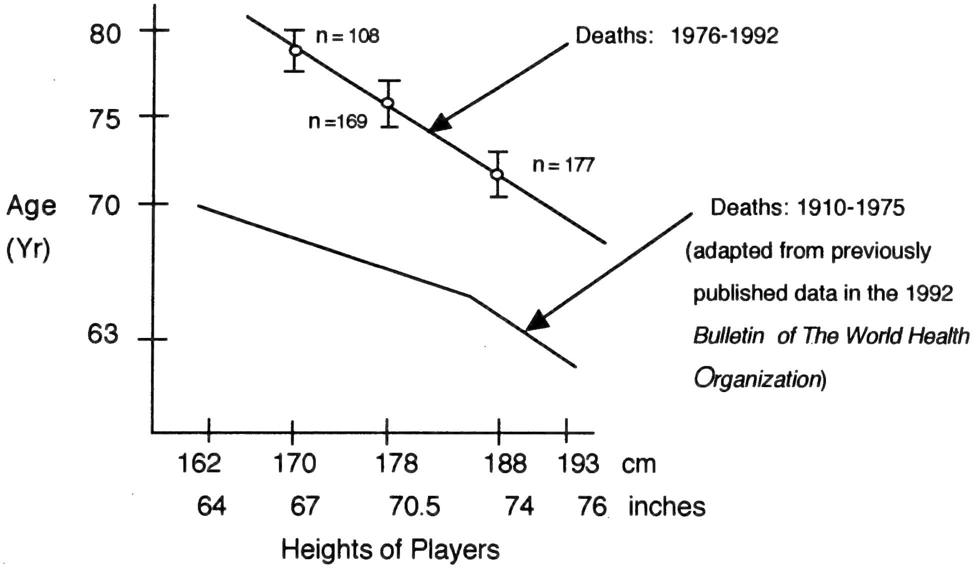
Notes: Each bullet represents the average age for a group of men equal to or above a certain height or below a certain height; the sample size (n) is shown to the right of each height.

Error bars = $\bar{x}$ +/– $s_{\bar{x}}$, where $\bar{x}$ = mean age, $s_{\bar{x}} = s/n^{1/2}$, $s_{\bar{x}}$ = standard error of the mean, s = standard deviation, and n = sample size

Fig. 1. Average life span in years vs height in centimeters and inches for 19th Century deceased French men.

An evaluation of longevity data on over 400 decreased French men and women (Topinard, 1888) showed that the average age at death declined with increasing height. Figure 1 depicts the average age at death versus height ranges for men. (This data was originally collected by Broca, a French surgeon.) Men and women showed in excess of a 6-year difference between the shorter and taller halves of men and women. The longevity vs height correlation coefficient for men was $r = -.21$ ($p < .005$) and for women $r = -.14$ ($p < .05$).

In 1995, a follow-up study on decreased professional baseball players was conducted using The Baseball Encyclopedia (Reichler, 1993). The study previously reported (Samaras and Storms, 1992) covered players who had died up to 1975. This follow-up study covered 450 players who died from 1976 through



Notes: Error bars = $\bar{x}$ +/− $s_{\bar{x}}$, where $\bar{x}$ = mean age, $s_{\bar{x}} = s/n^{1/2}$, $s_{\bar{x}}$ = standard error of the mean, s = standard deviation, and n = sample size

For players that died from1976 -1992, longevity for 67" players is the average longevity for players 5'5" - 5'9"; longevity for 70.5" player is average longevity for players 5'10" - 5'11"; and longevity for 74" players is the average longevity for players 6' - 6'4".

The sharp drop for deaths between 1910 and 1975 appears to be an anomaly based on the death pattern for players who died after 1975.

Fig. 2. Reduction of baseball player average life span with increasing in height.

1992. The results were similar to those of the previous study as shown in Figure 2. Note that the average longevity has risen considerably for all height groups. However, the shorter players still had significantly greater longevity. For height vs longevity, the correlation coefficient $r = -.27$ ($p < .005$) and for weight $r = -.30$ ($p < .005$).

Animal Research

Walford (1988) reported on numerous studies that have been conducted since the 1930's when McCay, Sperling, and Barnes (1943) found that they could double the maximum lifespan of mice by placing them on an energy restricted

but well-balanced diet soon after birth. Albanes (1988) also reported that dietary restriction slows the rate of cell division and this may extend an animal's lifetime. These studies have been duplicated with various animals by Masoro (1985) and others. Another recent study at St. John's University in New York City found that by reducing the amino acid methionine in the diet of rats resulted in a size reduction of 20 to 45% and an increase in lifespan of 45% (Jhanjiani, 1995). Ross (1976) indicated that body size at maturity was a good predictor of lifespan independent of dietary variables. He found that larger body size at maturity was correlated with increasing incidence of degenerative diseases as was found by Chen, et al. (1990) in the Chinese study previously described.

Gerontologist A. Comfort (1961) also found that within a species, the larger animals usually had shorter lifetimes. Common examples include horses and dogs. The larger African elephant also lives about 20 years less than the smaller Indian elephant. The engineering-biology team of McMahon and Bonner (1983) also reported that within a species, the very tall and heavy individuals generally have more foot, leg, and spinal problems and tend to have shorter lives.

Nutrition, Size, and Health

As was mentioned before, nutrition and growth tend to go together (Tretli, 1989). We have assumed that because our nutrition has sped up the growth and development of our children, it must be good. However, the World Health Organization (WHO) found just the opposite to be true. A WHO panel of 11 international nutritional scientists reviewed the literature and 150 background papers and concluded that radical changes in our food supply have been at the root of our modern epidemic of chronic diseases (Nutritional Reviews, 1990). They also observed that in almost every developing country in the world, diet-related chronic diseases are evolving as the new health problem as people abandon traditionally healthy diets in favor of affluent foods. This pattern is aggravated by the public's perception of what a good diet consists of and the belief that "good" food is the same as "rich" food. The affluent diet of developed countries was described as one with high consumption of energy-dense foods of animal origin and foods processed or prepared with added fat, sugar, and salt. The panel recommended a BMI of 20–22, a value much lower than our present value of 26. The panel concluded its report with the following caveat: ". . . chronic diseases are to a large extent manifestations of nutrient excesses and imbalances in the diet and are thus largely preventable. An epidemic of cancer, heart disease, and other chronic ills need not be the inevitable price paid for the privilege of socioeconomic progress." These findings were echoed by Colin Campbell (Radetsky, 1994) when he stated that we could eliminate up to 90% of our heart disease and cancer by going on a high quality, low-fat, plant-based diet.

The Tarahumara Indians previously discussed also present an interesting illustration of great physical strength and health with marginal food intake. Health and fitness physician, Harold Elrick (1978) studied these remarkable people with a team of other scientists. He found these small people had low-to-normal blood pressure, low resting pulse rates, optimal cholesterol and triglycerides levels, and no heart disease or diabetes. Yet, their diet was far below American standards for protein, kilojoules, vitamins, and other nutritients. Elrick also studied the inhabitants of a small village in Ecuador. These long lived people were free of heart disease and consumed only 5028 kj per day with a fat intake of 12 to 19%. As a result of studying thousands of healthy people throughout the world, Elrick found that the optimum diet was low in kilojoules, fat, carbohydrates, salt, cholesterol, and protein.

Survival

Industrial production has increased by 40 times since 1950 and a future population of 10 billion people living at current U.S. standards will generate about 400 billion tons of solid waste per year (MacNeill, 1990). At today's rate, global resources will become very scarce in future decades. If people continue to increase in body size, this will compound our waste and resource problems. An overview of how a population of larger people threatens our survival follows. In all examples, a population of 1.83 m, 86.4 kg people is compared to a population of 1.52 m, 50 kg people. It is assumed that buildings, cars, and furniture are scaled to their size and lifestyles are the same for both populations. Details are given in The Truth About Your Height (Samaras, 1994).

The consumption of food and water is proportional to body size. Taller people will consume roughly 73% more food and water. For the present U.S. population of 265 million, this would require an additional 180 million acres of farmland for the increased needs of taller people. With about $\frac{1}{3}$ of the world's arable land lost over the last 40 years (ZPG, 1995), the combination of population growth, body size, and reduced farm land creates a very dangerous scenario for mankind's future, which is projected to be 12 billion by 2050.

The annual increase of several key resources, such as aluminum, copper, coal, and steel, would be about 600 million tons per year for the taller U.S. population. This estimate would be much larger if all resources were considered. U.S. energy needs would increase by 40 quadrillion kj per year. Of course, the increase in resources would be much greater for the world at large, especially in coming decades when developing countries increase their consumption of resources above current modest levels.

The additional trash generated by a U.S. population of taller people would be 80 million tons per year. In addition, municipal wastes poured into our coastal

waters would increase by a several trillion liters per year. Pollution would increase by 50 to 70%, and the taller U.S. population would pump an additional 3 billion tons of carbon dioxide into the air each year.

The economic impact of a world of tall people will also be enormous. For the U.S. alone, about $3 trillion per year would be required to feed, house, entertain, and transport 265 million people. For example, a typical coast-to-coast airline flight will cost an additional $33000 (Samaras, 1994). The reason for this added cost is the lower number of taller passengers that can be carried on an airliner. Entertainment costs would also go up because fewer seats would be available for each performance due to larger bodies and longer legs. For example, the Yankee Stadium was built in the 1920's and renovated in the 1970's. The upgraded stadium contained 9,000 fewer seats because engineers had to account for an increase of 7.6 cm in the width of the fan's bottoms.

We now spend about $1 trillion in medical care. This is about 1/7 of our GDP. How long can a society continue to spend increasing amounts on health care when huge amounts of money are needed for scientific research, education, new energy sources, urban renewal, repair of aging city infrastructures, environmental clean-up, and restoration of forests and degraded farmland. Cleaning up polluted rivers, lakes, and oceans will also cost huge amounts. Based on the health record of Asians in California, smaller people raised on healthful diets and lifestyles could reduce medical costs by many billions per year.

The present picture of unbridled consumption of our resources poses a great threat to our survival. Over 50% of the original rainforests are now gone. We are cutting down 40 million acres of rainforest every year. At this rate, the San Diego Zoological Society predicts that there will be no rainforests in 50 or 60 years. Studies by the Intergovernmental Panel on Climate Change (Monastersky, 1995) has just shifted the threat of climate change from tentative predictions to certain forecasts. The panel projects a 1°C to 3.5°C increase in the world's temperature by 2100 with a rise in the sea level of 15 to 90 cm. As a result, flooding will displace up to 92 million people each year. Climate change will also cause significant loss of life through the spread of malaria and other diseases.

Discussion

While not many scientists favor slowing growth, some have begun to see the problems caused by the diet that is associated with increasing human size. For example, Walker, Walker, Glatthaar, and Vorster (1994) recently challenged the belief of many nutritional scientists that maximization of human growth and stature is a desirable goal. They pointed out that there is evidence which demon-

strates that lower energy intakes with resultant smaller body size may actually confer a degree of future protection against degenerative diseases, such as atherosclerosis and cancer. The WHO panel of 11 international nutritionists reported similar findings as described in the previous section. Additional support for their positions comes from our experiences during the Korean and Viet Nam wars. Autopsies of young American soldiers killed in battle showed that 40% of these men had significant clogging of their arteries. In contrast, native Korean and Vietnamese soldiers were found to be free of this problem. American researchers have found accumulation of fatty deposits in the arteries of children as young as 10 years old.

Confounding Factors and Epidemiological Studies

Many problems exist concerning epidemiological studies as described by Harvard professor Charles H. Hennekens. The health of human subjects reflects a mix of socioeconomic, hereditary, lifestyle, and nutritional factors. In addition, the mother's diet and alcohol consumption during pregnancy, congenital heart problems, rheumatic heart disease, ethnic background, and exposure to toxins and carcinogens play a role. For example, highly educated people tend to live 4 or 5 years longer than less educated people. Married people in some cases live 10 years longer than those who aren't—though single people with good social support networks probably do as well. Government and other researchers have found that there are more tall people in highly educated classes, and the educated smoke much less than those with less education. Educated people, such as Harvard alumni, also tend to have lower BMI's and better medical care. Also some short people experience growth problems due to congenital heart problems and other childhood diseases that curtail their life expectancy without any relation to their actual height. These factors can sometimes bias the findings of epidemiological studies in an unexpected way. However, most of these confounding factors would favor greater longevity for taller people. Therefore, the longevity findings of Storms, Samaras, and Miller are probably not biased in favor of short people due to confounding factors.

The use of the BMI is also another potential confounder. The BMI which is computed by dividing body weight in kilograms by height squared in meters has been found to be relatively independent of height in terms of reflecting obesity or overweight as excess fat. (Not all researchers agree that the BMI formula actually does this.) However, when short and tall people are compared using this standard, the result is to compare people that are not geometrically similar. For example, the ideal weight (midpoint) for a male 1.83 m is 73 kg. The weight of a 1.52 m person, however, is set at 51 kg. If geometrically similar men were compared, a 1.83 m male should weigh 15.4 kg more or 88.4 kg. Thus, most

studies compare short mesomorphic-endomorphic people to tall ectomorphs instead of comparing short and tall people of the same geometrical configuration. Short people should be compared to tall people with BMI's 2 to 4 points higher or a different BMI formulation should be used, such as the Samaras Index (Samaras, 1994) or the Ponderal Index, which was developed years ago but has now been discarded in favor of the BMI formula used in most modern mortality and morbidity studies.

Conflicting Findings

As most people know, conflicting findings exist for many studies. Earlier European and American studies found short people had a high coronary heart disease mortality. These studies; e.g., Barker (1990), found that taller people had a lower mortality from heart disease and strokes. However, recent studies by Hebert et al. (1993), Kannam et al. (1994), a Swedish study, and an unpublished report by the University of Tennessee found essentially no difference in heart disease mortality for short and tall people. Similarly, not all cancer studies have found positive correlation between height and cancer mortality or morbidity.

There is a plausible explanation for the idea that short people have more heart attacks. For example, short people in wealthy countries overeat due to the abundance of food and the fact that portions tend to be designed to meet the needs of average size people. Thus, small people tend to become overweight. Also, smaller people tend to have smaller diameter arteries and blood vessels. These vessels would tend to become blocked more quickly due to high fat diets. Another factor may be the relatively larger surface area of the shorter person's small intestine is likely to absorb more nutrients from food than a tall person. (As mentioned before, the surface areas, including the intestine, of a 1.83 m person are only 44% larger compared to a body weight of 73%.) Thus, short people are at increased risk for heart trouble if they eat excessively and put on weight compared to when they were 18 years old. But shortness by itself does not appear to be a problem in view of the lower heart disease mortality for the Japanese, Chinese, American Asians and Hispanics, Tarahumara Indians, and women in general.

Possible Causes for Increased Cancer in Taller People

A 1.83 m person has about 100 trillion cells in his or her body. A 1.52 m person would have only 60 trillion cells. Thus, a tall person has an additional 40 trillion cells where cancer can be initiated. Free radicals caused by metabolic processes, radiation, toxins, and physical and emotional stress would have more opportunity to initiate a cancer event. Perhaps the large increase in skin cancer is partially related to our larger skin surface which is exposed to UV radiation.

High-energy cosmic ray exposure of an additional 40 trillion cells may also add to carcinogenic mutations. Albanes (1988) proposed this explanation for increased cancer in taller people several years ago and theorized that nutritional restriction early in life permanently reduces organ cellularity. Perhaps this is why cancer researcher Robert Good (Segerberg, 1974) found Australian aborigines on low protein diets showed strong resistance to cancer. However, he found that the protein restriction had to be severe enough to retard growth and maintained throughout life.

Possible Reasons for greater heart problems

For geometrically similar short and tall people, the heart and blood volumes are proportional to body weight. However, the taller person's heart has to do disproportionately more work than the shorter person's heart. The reason for this is that the tall person's heart must not only pump 73% more blood through the body, but must pump it 20% farther. Thus, the taller person's heart does 2.08 times more work but is only 1.73 times larger. Another possibility may be that the taller person's relatively smaller lung surface area may not always provide as much oxygen as needed to the heart with possible long-term damage.

Theory predicts that blood pressure should be the same for geometrically similar people of different heights. However, some studies have found a slight increase in systolic blood pressure or in both systolic and diastolic pressure with height. It is thus possible that a slight life-long increase in blood pressure could be harmful to the heart.

On the other side, taller people should have lower heart rates than shorter people according to Astrand & Rodahl (1986). Lower heart rates have been found to promote longer life and would appear to be a positive factor. Fitness experts recommend resting heart rates of less than 60 beats per minute. This advantage would reduce the work load on a taller person's heart.

Brain Size and Intelligence

As mentioned before, some scientists have found that brain size and intelligence are positively correlated and others have challenged this position. If a correlation is found, it will most probably be related to socioeconomic class and taller stature as was mentioned before (Sandberg, 1995). Even if a real difference in IQ were found, it would not be an important factor in survival of humankind. Our problems stem mainly from lack of wisdom and self-discipline, self-absorption, and ignorance. IQ is probably not the root cause of human failure because people with normal intelligence have a great capacity to function well if they have the proper motivation, education, and training.

Health Risks of Dietary Restriction

Traditional beliefs indicate that undernutrition is dangerous to the health of our children and ourselves. Certainly malnutrition is not good for anyone. But there's considerable evidence to indicate that a sparse but well-balanced diet promotes good health. For example, during WW II Strom and Jensen (1951) reported that food in Norway became scarce, and the shortage was primarily of high fat and cholesterol foods, such as meat, milk, butter, cheese, eggs, and sugar. The average energy intake dropped 18%. At the same time stress increased due to the German occupation. Yet, there was a sharp fall in mortality for males and females in all age groups. After the war, mortality rose sharply when traditional dietary practices were resumed. Food restriction during the war resulted in similar patterns, including drops in breast cancer, for Denmark, England, Wales, and Holland.

Another study by Spanish physician Vallejo (Walford, 1988), reduced the energy intake of 90 patients over 65 years old at a nursing home in Madrid, Spain. One day he fed the group 9637 kj and the other day 3708 kj. A control group of 90 patients was fed 9637 kj every day. This 3-year study found that the lower kilojoule patients had half the mortality of the normally fed group, and the members of the lightly fed group spent 123 days in the infirmary compared to 219 day for the group with a higher food intake.

Dubos (1980) participated in a nutrition research in Guatemala. He found the natives were very sparsely fed compared to our standards and many children and youth died of infections. However, those who survived to adulthood were capable of much greater work output compared to larger Europeans and North Americans, such as "carrying heavy burdens on their backs over long distances up and down mountains". They were short and seemingly frail but they were healthy and lived to a good old age.

Kagawa (1978) found that Okinawan children received 40% fewer kilojoules than mainland children. Adults consume about 20% fewer kilojoules. Yet, Okinawans have about half the mortality of mainland Japanese and more centenarians than anywhere else in the world. They are also the smallest of the Japanese. Kagawa concluded: ". . . westernization of the Japanese diet may be beneficial provided rice, fish and vegetables are kept as major foods and salt, sugar, cholesterol, saturated fats and total energy are restricted."

During a 12-year study, Murray et al. (1992) found that chronic undernutrition in adult Masai did not negatively affect their health. The undernourished of group 403 Masai had BMI's of about 18.5 for men and 16.6 for women. The normally nourished group of 386 Masai had BMI's of about 20.4 for men and 18.2 for women. While none of the Masai (18–35 years of age) died of illness, the

normally nourished had 4 times the malarial attacks and 2 times the infections. Five normally nourished Masai were struck by malignant tumors whereas none of the undernourished had them. The normally nourished were also incapacitated 2.4 times more days per year compared to the undernourished.

Environmental Threats

Benjamin H. Alexander (1989) observed that the world's population is our number one pollution problem. He also observed that smaller size humans would help conserve our resources including water, which is so vital to our existence. He believes that if we do not reduce the size of humans, the most powerful people in our world will take control and billions of people could be killed outright to reduce the world population. Billions more, he feels, could be enslaved. Although this is an unpleasant scenario, the works of many autocrats, such as Hitler and Stalin, provide ample evidence that it can happen very quickly when conditions are right.

The former chief scientist of the National Oceanographic and Atmospheric Association, Sylvia Earle (1995) observed that "Depending on the choices we make, our species may be able to achieve a viable, sustainable future or we may continue to so alter the nature of our planet that our kind will perish." We are all aware of the need to reduce population growth, pollution, overfishing, deforestation, and loss of arable land. One way to minimize the damage that Earle is concerned about is to reduce the size of the average human on earth.

How Should People Respond to These Findings

The value of any person is totally unrelated to his or her size. Therefore, no one should feel superior or inferior due to their height. Our value to society and self respect should depend on how we behave towards our fellow humans and other life forms and what contributions we make to improve our society and world. Since those of us living today can't change our heights, our response to these findings should be to encourage a change in our current attitudes so that the world will be receptive to future generations of smaller people.

As mentioned, stature is a small part of the total picture affecting an individual's longevity. Regardless of one's height, good health practices are much stronger factors in determining how long anyone will live. It appears that the recommendations of epidemiologist Tim Byers (1995) apply to how we should view our stature on a personal level. Except for large weight gains, he observed that studies demonstrating the impact of small weight increases on mortality have a relatively small impact in terms of an individual's lifespan. Unfortunately the public over-

reacts to various health and nutrition findings, and most people become frustrated with their attempts to lose weight because they cannot attain or maintain the very low body weights recommended. Byers rightly recommends that we should be focusing on more important aspects of good health, such as regular exercise and good nutrition. However, as described in this paper, additional emphasis is needed on low-energy and high fiber diets, avoidance of smoking and excessive drinking, stress management, and work satisfaction. Leading nutritional scientists, such as Harvard's Walter Willett, recommends that we should eat lots of fresh fruits and vegetables because extensive research shows they protect against cancer and heart disease. He also recommends eating red meat no more than once a week. These practices are probably more important to one's health than focusing solely on attaining one's ideal weight. However, lower weight is also important, but it should be achieved by a permanent change in lifestyle. Therefore, being very tall should not be viewed with alarm if good health practices are followed. Samaras' studies found many tall and large men who lived into their 80's and 90's. However, weight control is a very important strategy for tall people.

Impact of Longer Living People on Environment and Economy

Analysis of the impact of longer living short people indicates that the cost would be almost $400,000 less for a postulated 12-year longer lifespan (Samaras, 1994). Resource consumption would be about 50 to 73% less over a lifetime, which would more than compensate for the 17% longer lifetime. Therefore, a population of longer living short people would not neutralize their benefits. In addition, able bodied retired people could support many worthwhile environmental and social projects.

Delaying Puberty

According to Foster, a neuroendocrinologist, a high kilojoule diet is propelling American girls and boys into sexual maturity sooner (Discover, 1995). The average age for the start of menstruation is now 12.5 years, down from 14 years in 1900. Among hunter-gathers societies menstruation occurs at 16. In our complex world, early sexual maturation aggravates our social problems because the children have not had enough time to gain in wisdom and self-control. As Benjamin H. Alexander (1989) has said, their lives could be improved by delaying the onset of hormonal changes that can be distracting from school work and a more gradual maturation process. This delay would probably also help parents maintain better control of their children for a longer period than they now have. The

possible benefits would be fewer teenage pregnancies, less anti-social behavior, and fewer ruined lives.

Conclusion

Virtually all of us have been conditioned to believe that taller and bigger is better than shorter and smaller. Parents often brag about their children growing rapidly and being taller than their peers. Yet, we never hear parents proudly proclaim that their children are growing up short and light. Unfortunately this deep-seated bias is not based on good science. Smaller people can be just as physically and mentally fit as taller people. In addition, a population of smaller people offers one path to reducing the damage we will wreak on the planet in the coming years. As illustrated in the previous sections, smaller people require much less of almost everything and can help assure a good life for ourselves, children, and grandchildren. If we plan to populate the planet indefinitely, smaller people will allow us to achieve this goal.

William Conner (Liebman, 1995), a heart disease expert at the Oregon Health Sciences Center, reported that pre-affluent Japan had $\frac{1}{8}$ the heart disease death rate that we have now. Today the Japanese are bigger and taller and have closed the gap so that they have only $\frac{1}{2}$ the death rate of what the U.S. has. Is this a good trade-off? Wouldn't our children be better off in a society where everyone was smaller and healthier? Perhaps the only one who can answer this question is someone who has suffered from cancer or heart disease, its treatment, and after-effects.

We have the ability to reduce the size of future generations now. According to Walford (1986), we could reduce height by up to 20 cm through dietary restriction. However, psychosocial resistance to evolving smaller size children is very strong. Achievement of this goal will require wide-scale public education to achieve an appreciation of the benefits of smaller human size.

The choice to become smaller may not be a future option, and we may simply become smaller due to the scarcity of rich or energy-dense foods. The American Association for the Advancement of Science (Krajick, 1995) reports that food shortages in the next 50 years will become quite severe. Meat, milk, eggs, and butter will become rare, and we will have to eat more simple foods that come directly from the earth. In view of this anticipated shortage, food scientists have an important mission to develop highly palatable substitutes for regular and fast-food fare which are low in kilojoules and fat but high in vital nutrients and fiber. They have already achieved some outstanding results in producing good tasting vegeburgers and by substituting cellulose in baked goods, reducing the energy content significantly.

Scientists concerned with our survival say that we can't continue to expand our population on an earth of finite size. Actually, the earth is getting smaller. Certainly its mass is not changing, but the arable land and terrestrial and oceanic resources are declining as massive human consumption converts more and more resources into degraded materials that are no longer available for human use. Economist Georgescu-Roegen (1971) said many years ago that the entropy of the earth is irreversibly increasing as we convert natural resources into disordered matter. He also pointed out that "bigger and better" washing machines, automobiles, and superjets lead to "bigger and better" pollution. It appears that "bigger and better" people also increase the earth's entropy and reduce the human race's chances for long-term survival. Our planet cannot afford the luxury of supporting 12 billion people averaging 77 kg—the average weight of today's middle-aged Americans.

Postnote

The research presented in this paper was initiated as a byproduct of the application of the second law of thermodynamics (law of entropy) to human organizations and their tendency to become disordered with time (Samaras, 1973). This law was interpreted to mean that as an organization grows in size and energy content (money), it tends to become increasingly disordered unless energy is expended on internal operating systems to restore them to proper order. This application of the entropy law was then applied to human aging (Samaras, 1974). This theory hypothesized that aging (progressive disorder) is accelerated over time as a function of the mass and energy consumption of the body. The thermal physics expression $\sigma = \log g\ (N, U)$ was used as a basis for increasing disorder. The symbol σ refers to entropy and, g, the number of possible states that a system (the body) can be in. The number of states that a system can be in increases with the number of body cells (N) and the average daily energy of the system (U). Thus, to minimize aging, the optimum body configuration would be one in which the combination of body mass and energy needs would be minimized. From this beginning, research proceeded from longevity studies to evaluation of body size on performance, resource, energy needs, and survival (Samaras, 1978).

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Locality, Realism, Lorentz Invariance and Quantum Mechanics

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ABSTRACT

Quantum mechanics is a powerful predictor of physical phenomena, but all attempts to incorporate it with traditional characteristics of scientific theories have proved unsuccessful. This paper reviews the incompatibility of quantum mechanics with so named local realistic theories of nature. It goes beyond the Bell statistical inequality to demonstrate that the Hardy two particle condition produces logic contradictions that prevent realistic theories from being consistent with quantum mechanics if they are not only non-local, but also non-Lorentz invariant. The paper questions these contradictions. In particular, it examines two experimental conditions, state preparation and detector efficiency, to demonstrate that under less than ideal conditions, the Hardy contradictions reduce to, at best, the less direct Bell statistical contradictions. The paper concludes with the suggestion that the failure to experimentally reproduce these logical contradictions may be yet another manifestation of the Uncertainty Principle protecting nature from humanity's discovery of its secrets.

Quantum mechanics is a major cornerstone of twentieth century science. By all standards, it has had astonishing success in predictions of behavior on the atomic, nuclear, and elementary particle scale. Recent attempts have been made to extend quantum mechanics to a quantum cosmology to understand the creation of the Universe itself. Despite its scope and achievements quantum mechanics remains an unsettling description of nature, placing demands that appear counter intuitive and producing results that seem baffling to all who try to use it to comprehend the physical world. This paper will illustrate the contradictory nature of quantum theory when attempts are made to incorporate it with traditional attributes of physical theories. The paper will examine experimental limitations that present obstacles in demonstrating these contradictions and suggest, perhaps, there is a fundamental limitation in our human ability to observe these bizarre behaviors.

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I. Local Realism and Quantum Mechanics

At the center of quantum theory is the Heisenberg Uncertainty Principle which sets restrictions on the ability to precisely measure **conjugate** variable pairs, such as position and momentum or spin in two orthogonal directions, simultaneously. For example, if Δp is the uncertainty in momentum and Δx is the position's uncertainty, the product of their uncertainties is expressed as the following inequality:

$$\Delta p \Delta x \geq \hbar/2 \tag{1}$$

where $\hbar = h/2p$, h is Planck's constant (6.63×10^{-34} joule-sec).

Eq. (1) illustrates the inverse relation between the two observables' uncertainties. The smaller the uncertainty in one of the variables, the larger the uncertainty in the other so that their product satisfies the inequality. Therefore, the Uncertainty Principle claims making measurements to determine precisely a physical observable always disturbs its corresponding conjugate variable. Due to the intrinsic vagueness, a probablistic interpretation is used that replaces the classical deterministic view of understanding nature.

In the development of quantum theory, several of its founders were troubled by these aspects of it, none perhaps more than Albert Einstein. After first trying to refute quantum mechanics on consistency, Einstein looked to demonstrate quantum mechanics was not a complete theory of nature. In a paper with colleagues Boris Podolsky and Nathan Rosen, Einstein (1935) suggested a thought (Gedankan) experiment that forced quantum mechanics to violate a seemingly irrefutable assumption of nature.

The EPR paradox, as it became known, employs a system consisting of two particles that are strictly correlated (**entangled**) with each other, such that properties about the entire state are known (i.e., total momentum). This property of the entire system enables one to use measurements on one particle in one place, to deduce the corresponding property of the other without disturbing its conjugate observable.

For example, consider two particles (1 and 2) which are initially together at rest. If they are forced apart by some reaction, we can still conclude that their total momentum is zero. If the momentum of particle 1 is measured, by conservation of momentum, the momentum of particle 2 would be known, without disturbing its position. Quantum mechanics would not allow this to happen. It would, therefore, claim measuring particle 2's momentum disturbed its position, which affected particle 1's position. Thus, in order to prevent a violation of the Uncertainty Principle, there would have to be an instantaneous transfer of information from one particle to another affecting the corresponding observable.

EPR considers this a violation of **locality** in that "no reasonable" theory of nature would allow a measurement of one object at one place to affect the

measurement of another object at a different place. EPR then claims, to obtain the predictions of quantum mechanics, objects must have pre-existing conditions or hidden variables that determine the outcomes of measurements. These are called hidden variables or **realistic** theories. These hidden variables are considered **elements of reality** that exist independent of a physical measurement. Quantum mechanics is thus considered a statistical approximation to much more complete realistic theories that do not have to resort to non-locality.

It was assumed by EPR that these local realistic theories once found would be consistent with the predictions of quantum mechanics. That assumption was shown to be untenable by John Stewart Bell (1964). Bell proved mathematically that no local realistic theory could always give the same predications as quantum mechanics in a two particle, strictly correlated state. An example of such an entanglement would be two spin 1/2 particles with total spin 0. Bell's Theorem is an inequality relationship among probabilities of measurement of observables for this system along different directions, derived under the assumption of local realism. Quantum mechanics exhibits a statistical disagreement with this inequality, indicating that local realistic theories would differ with quantum theory a certain fraction of the measurements. These violations set up a criteria for testing local realistic theories against quantum theory. In a series of experiments (Freedman & Clauser (1972), Clauser (1976), Fry & Thompson (1981), Aspect et al. (1981), Aspect et al. (1982), Ou & Mandel (1988), Lamehi-Rachti & Mittig (1976)) quantum theory has consistently been validated.[1]

A strengthening of the conditions producing a violation was derived by Greenberger, Horne, Shimony, and Zeilinger, GHSZ (1990). In looking at three or more particles in strictly correlated states, GHSZ obtained, assuming local realism in quantum mechanics, statements in direct contradiction without the use of Bell inequalities. The violation is such that it would occur with each individual measurement, and not, as in Bell's proof, only be evident on a statistical basis.

Lucien Hardy (1992, 1992a, 1993) has devised thought experiments on two particle systems which demonstrate the contradiction of local realistic theories with quantum theory also without inequalities, but, unlike GHSZ, occurring some of the time. In order to achieve this violation, Hardy prepares states or arranges apparatus of experiment such that one term is missing from the complete state expressed in some basis. He calls these states **non-maximally** entangled. In addition, Hardy is able to demonstrate that realistic theories are not **Lorentz invariant**.

In order to demonstrate the previous statement, consider these definitions taken from Hardy (1992):

—Locality: Measurements in one place on a single object can not affect measurements at another place on another object simultaneously.

—Realism: If you can predict with certainty (probability 1) the result of a physical measurement, then there exists an element of reality corresponding to this physical quantity and having a value equal to the predicted measurement result.
—Lorentz Invariance: The value of an observable is frame independent. The value of an element of reality corresponding to a Lorentz invariant observable is itself invariant.

Hardy proceeds to demonstrate realistic theories must be non-local if they are to agree with quantum mechanics for thought experiments involving positron-electron pairs (1992) and photon pairs generated by degenerated parametric down conversion (1992a). Clifton and Niemann (1992) generalize this argument to two entangled spin singlet states.

Hardy (1992) also shows realistic theories of quantum mechanics are not Lorentz invariant for an interference experiment involving electrons and positrons. In this study I will generalize by using Hardy's non-maximally entangled state vector (1993) to demonstrate non-Lorentz invariance for realistic theories of quantum mechanics. I will then examine some of the implications of trying to avoid this contradiction.

II. Non-Lorentz Invariance for Hardy State

Consider a particle that has an observable that can take on one of two values, say + or −.

$| + >_1$ represents particle 1 in state with observable value +

$| - >_2$ represents particle 2 in state with observable value −

These states are represented in the traditional Dirac notation $| >$.

Assume in an entangled condition two such particles must have the same value of this observable, either both + or both −. They can never be in the condition where one of the particles has this value of this observable + and the other's corresponding value is −. Therefore, the states $| + >_1 | - >_2$ and $| - >_1 | + >_2$ can never occur.

Looking at Hardy's state for any two particle entangled system with **basis states** $|\pm>_i$ $(i = 1, 2)$

$$\psi = \alpha | + >_1 | + >_2 - \beta | - >_1 | - \rangle_2 \qquad (2)$$

where ψ is the complete state of the entangled system and

$$\alpha^2 + \beta^2 = 1 \qquad (3)$$

$| + >$ and $| - >$ can be decomposed into basis vectors $|u_i\rangle$ and $|v_i>$ which represent intermediate states that can be subject to observation.

$$| + >_i = b|u_i> + ia^*|v_i> \tag{4a}$$

$$| - >_i = ia|u_i> + b^*|v_i> \tag{4b}$$

where $|a|^2 + |b|^2 = 1$
Prepare the state such that the coefficient in front of the $|u_1> \; |u_2>$ term is set equal to zero.

$$\alpha b^2 + \beta a^2 = 0$$

thus

$$a^2/\alpha = -b^2/\beta$$

Using Eqs. (4a) and (4b) in Equation (2)

$$\psi = -[\surd(\alpha\beta)|u_1>|v_2> + \surd(\alpha\beta)|v_1>|u_2> + (|\alpha> - |\beta>)|v_1>|v_2>] \tag{5}$$

Then vectors $|u_i>$ and $v_i>$ can be decomposed into basis vectors $|c_i>$ and $|d_i>$ which represent final measurement states.

$$|u_i> = A^*|c_i> - B|d_i> \tag{6a}$$

$$|v_i> = B^*|c_i> + A|d_i> \tag{6b}$$

where

$$A = \surd(\alpha\beta)/\surd(1 - \alpha\beta) \tag{7a}$$

$$B = (|\alpha| - |\beta|)/\surd(1 - \alpha\beta) \tag{7b}$$

and

$$|A|^2 + |B|^2 = 1$$

Now consider physical observables $\hat{U}_i$ and $\hat{D}_i$ with corresponding operations

$$\hat{U}_i = |u_i> <u_i| \quad \text{and} \quad \hat{D}_i = |d_i> <d_i|$$

Since they are **projection operators**, their respective physical quantities can only take on values 0 and 1 corresponding to the eigenvalues of $\hat{U}_i$ and $\hat{D}_i$. From the definition of realism, we claim that if

$$\hat{U}|u> = 1|u> \quad \text{then } U = 1$$

where the symbol U represents with probability 1 that the value of measuring the corresponding $\hat{U}$ equals 1.

Now consider a measurement in the laboratory reference system such that measurements on particles 1 and 2 occur simultaneously. From Equation (5)

$$\hat{U}_1\hat{U}_2|\psi> = 0$$

since, as designed, there is no $|u_1>|u_2>$ term in Equation (5).

Then from the ideas and notation above, we can conclude with probability 1 that

$$U_1U_2 = 0 \tag{8}$$

This result implies that U_1 and U_2 can not be both 1 simultaneously.

Now, change reference systems into one in which particle 2 splits into $|d_2>$ and $|c_2>$ before particle 1 splits into $|d_1>$ and $|c_1>$. Using Equations (6a) and (6b), the state vector Eq. (5) is written as

$$\psi = -[B^*\surd(\alpha\beta)|u_1>|c_2> + \alpha\beta A|u_1>|d_2> + (\surd(\alpha\beta)A^* + (|\alpha| - |\beta|)B^*)|v_1>|c_2>] \tag{9}$$

There is no $|v_1>|d_2>$ term, since its coefficient $(|\alpha| - |\beta|)A - \surd(\alpha\beta)B = 0$

From Equation (9), if we measure D_2 to be 1 on particle 2, then U_1 must be 1 on particle 1 since only the $|u_1>|d_2>$ contains $|d_2>$

$$\text{In other words} \quad \text{if } D_2 = 1 \quad \text{then} \quad U_1 = 1 \tag{10}$$

Similarly, if we choose a reference system such that particle 1 splits before particle 2 splits, the state of the system can be written as

$$\psi = -[(\surd(\alpha\beta)A^* - (|\alpha| - |\beta|)B^*|c_1>|v_2> + \surd(\alpha\beta)B^*|c_1>|v_2> + \surd(\alpha\beta)A|d_1>|u_2>] \tag{11}$$

In the case there is no $|d_1>|v_2>$ term because coefficient

$$-B\surd(\alpha\beta) + (|\alpha| - |\beta|)A = 0$$

By the same reasoning as in Equation (9), we see from Eq. (11)

$$\text{If } D_1 = 1 \quad \text{then} \quad U_2 = 1 \tag{12}$$

where in Equation (12) the same condition of reality is used.

Quantum mechanics is Lorentz invariant at the level of its statistical predictions in any frame. Detection (or non-detection) of an observable should be independent of the reference frame the observable is measured in. Since these observables exist independent of the measurement system, we can compare them.

To this end, consider an experiment in which D_1 equals 1 and D_2 equals 1. From Equations (5) and (6a-b)

$$\psi = -[2\sqrt{(\alpha\beta)}B^*A^* - (|\alpha| - |\beta|)B^{*2}]|c_1\rangle|c_2\rangle + [\sqrt{(\alpha\beta)}A^*A - \sqrt{(\alpha\beta)}B^*B + (|\alpha| - |\beta|)B^*A]|c_1\rangle|d_2\rangle + [-\sqrt{(\alpha\beta)}BB^* + \sqrt{(\alpha\beta)}AA^* + (|\alpha| - |\beta|)AB^*]|d_1\rangle|c_2\rangle + [-2\sqrt{(\alpha\beta)}BA + (|\alpha| - |\beta|)A^2]|d_1\rangle|d_2\rangle \tag{13}$$

Since the coefficient in front of $|d_1\rangle|d_2\rangle$ is not zero, there is a finite probability (maximum about 9% (Hardy, 1993) of this state in Equation (13) occurring.

For experiments that satisfy Equation (13), we obtain from Equations (10) and (12)

$$\text{If } D_1 = 1 \quad \text{and} \quad D_2 = 1, \quad \text{then} \quad U_1 = 1 \quad \text{and} \quad U_2 = 1 \tag{14}$$

therefore

$$U_1U_2 = 1 \tag{15}$$

which is in direct contradiction to Equation (8).

Therefore, realistic theories can not be consistent with quantum mechanics unless they are non-local and non-Lorentz invariant.

III. Examination of Experimental Conditions

To avoid this contradiction, some difficult choices have to be made. One possibility is to abandon realism and with that the notion of elements of reality existing independently of measurement. This has been called the Copenhagen Interpretation. The adoption of this positivist view of nature remains a reluctant alternative to many.

Another possibility is to assume instantaneous transfer of information between objects in spacelike intervals. Abner Shimony (1990) argues that quantum mechanics does not violate parametric independence which forbids superluminal transmission of signals but violates outcome independence which allows subluminal transmissions. On the other hand, Ferrero, Marshall and Santos (1990) claim that special relativity not only forbids faster than light signaling but also forbids faster than light actions at a distance.

An alternative is to suggest from the non-Lorentz invariance there exists a privileged frame of reference in which realistic (hidden variable) theories are always applied. Thus, hidden variable theories would be in violation with the tenants of Special Relativity. How this privileged frame would be determined remains an open question.

Another approach, more pragmatic, is to examine the experiments themselves.

Can experimental limitations avoid the contradiction? There are two possible mechanisms for this to occur.

A. Difficulty in preparing the state properly: This would involve guaranteeing the Hardy state vector, both in the set up of the apparatus and the preparation of the state vector.
B. Detector inefficiencies: This involves the ability for real laboratory instruments to detect outcome pairs coincidentally.

Failure of either A or B would not ensure the conditions expressed in Equations (8), (10), (12) and (14) to be met exactly. It will be shown that these failures reduce the Hardy contradictions to, at best, Bell statistical inequalities and may indicate a fundamental limitation in comparing local realistic theories with respect to quantum mechanics.

To demonstrate the conditions when realistic theories give a contradiction with quantum mechanics, let λ be the set of hidden variables. Then for

$$U_1(\lambda)U_2(\lambda) = 1 \tag{16a}$$

$$U_1(\lambda)U_2(\lambda) = 0 \tag{16a$'$}$$

$$D_1(\lambda)U_2(\lambda) = 1 \tag{16b}$$

$$U_1(\lambda)D_2(\lambda) = 1 \tag{16c}$$

$$D_1(\lambda)D_2(\lambda) = 1 \tag{16d}$$

Let

S_{U1U2} be the set of all λ's such that Equation (16a) holds.

S'_{U1U2} be the set of all λ's such that Equation (16a′) holds.

Note, Equation (16a′) allows

$$U_1(\lambda) = 0 \text{ and } U_2(\lambda) = 0 \Rightarrow S_{U1'U2'}$$

or

$$U_1(\lambda) = 0 \text{ and } U_2(\lambda) = 1 \Rightarrow S_{U1'U2}$$

or

$$U_1(\lambda) = 1 \text{ and } U_2(\lambda) = 0 \Rightarrow S_{U1U2'}$$

$$S'_{U1U2} = S_{U1'U2'} + S_{U1'U2} + S_{U1U2'} = \overline{S}_{U1U2}$$

where $\overline{S}_{N1N2}$ is the complement of S_{N1N2} (where $N_i = D_i$ or U_i $(i = 1, 2)$), the set of all λ's not belonging to S_{N1N2}.
In addition, let

S_{D1U2} be the set of all λ's such that Equation (16b) holds.

S_{U1D2} be the set of all λ's such that Equation (16c) holds.

S_{D1D2} be the set of all λ's such that Equation (16d) holds.

A. Difficulty in State Preparation: Using Hardy's analysis (1992) a contradiction would still be produced if

$$P(\bar{S}_{U1U2}/S_{D1D2}) + P(S_{D1U2}/S_{D1D2}) + P(S_{U1D2}/S_{D1D2}) > 2 \tag{17a}$$

and

$$P(S_{D1D2}) > 0 \tag{17b}$$

where $P(S_{N1N2}/S_{D1D2})$ is the probability of S_{N1N2} given condition S_{D1D2} is true.

B. Detector Inefficiencies: The second experimental limitation deals with detector efficiency. This loop-hole, as it is referred, can sometimes be ignored by claiming **fair sampling**. By fair sampling it is assumed that all detectors are identical and operating at the same efficiency. Therefore, the number of detections at one detector is proportional to the number that would be measured if the detector was ideal with the same constant of proportionality for all measuring devices. Under this condition probability relations among separate pairs of measurements remain the same as under ideal conditions.
Without fair sampling, the contradictions can still be analyzed using the following method of analysis by GHSZ (1990).
For **no** contradiction, relationships in Equations (16a-d) can be expressed as

$$\bar{S}_{U1U2} \subseteq (\bar{S}_{D1U2} \cup \bar{S}_{U1D2} \cup \bar{S}_{D1D2}) \tag{18}$$

Using probabilities this becomes

$$P(\bar{S}_{U1U2}) \subseteq P(\bar{S}_{D1U2} \cup \bar{S}_{U1D2} \cup \bar{S}_{D1D2}) \tag{19}$$

Using the condition that $(\bar{S}_{D1D2}, \bar{S}_{U1D2}, \bar{S}_{D1D2})$ may not be mutually exclusive

$$P(\bar{S}_{U1U2}) \leq P(\bar{S}_{D1U2}) + P(\bar{S}_{U1D2}) + P(\bar{S}_{D1D2}) \tag{20}$$

Since

$$P(\bar{S}_{U1U2}) = P(S_{U1'U2'}) + P(S_{U1'U2}) + P(S_{U1U2'})$$

therefore,

$$P(\bar{S}_{U1U2}) > P(S_{U1'U2'})$$

Then

$$P(S_{U1'U2'}) \leq P(\bar{S}_{D1U2}) + P(\bar{S}_{U1U2}) + P(\bar{S}_{D1D2}) \tag{21}$$

To account for detector inefficiencies, assume for simplicity the fraction detected by all detectors for all outcome pairs is f. For example, assume the rate of particles 1 and 2 are known and for D_1 and U_2 there are a fraction of these that are detected with $D_1 = 1$ and $U_2 = 1$. Call that fraction f

$$f \leq P(S_{D1U2}) \leq 1,$$

therefore,

$$P(S_{D1U2}) \geq f \tag{22a}$$

$$P(\bar{S}_{D1U2}) < 1 - f \tag{22b}$$

Use similar bounds for S_{U1D2} and $S_{U1'U2'}$

$$P(S_{U1D2}) \geq f \tag{23a}$$

and

$$P(\bar{S}_{U1D2}) < 1 - f \tag{23b}$$

$$P(S_{U1'U2'}) > f \tag{24}$$

For S_{D1D2} we have that the maximum probability is approximately 9% (Hardy, 1993), so

$$P(S_{D1D2}) > .09f \tag{25a}$$

and

$$P(\bar{S}_{D1D2}) < 1 - .09f \tag{25b}$$

Using Equation (21)

$$f \leq P(S_{D1D2}) < 1 - f + 1 - f + 1 - .09f \tag{26}$$

$$f < .971$$

To violate this inequality $f \geq .971$. Assuming each detector has efficiency ξ, then for two measurements (ex. D_1 and U_2), $f \cong \xi^2$

Therefore,

$$\xi \geq .985$$

IV. Conclusion

Thus, to demonstrate that realistic theories violate locality and Lorentz Invariance, the detectors must have efficiency > 98.5%. Notice that in both conditions of experimental limitations, Eqs. (17) and (20), Hardy's direct contradiction is replaced by a Bell-type inequality. Furthermore, if detector efficiency is not very high (< 98.5%), **no** violation of realistic theories with quantum mechanics is evident.

From this analysis it becomes evident that this contradiction, although stronger in principle than Bell's inequality, is very difficult to realize in practice. Furthermore, Emilio Santos (1992) states there is a fundamental incompatibility in experimental limitations A and B. Requirements of high detector efficiency and ideal state preparation are not simultaneously realizable. Santos argues that in most of these tests of Bell-type contradictions with quantum mechanics the state preparation involves the analyzing ability of devices such as polarizing filters for photons and the efficiency of detectors such as photocells. The polarizers rely on the wave properties of the detected quantum states, and the photocells rely on the particle properties. Santos tries to demonstrate that the correlation of the analyzers

decreases with detector efficiency, and the greater the analyzing ability the more difficult it is for detector efficiency to show a Hardy type contradiction.

Can it be that nature "protects" hidden variables in a manner similar to the way the Heisenberg Uncertainty Principle protects quantum mechanics from attempts to show it is contradictory? If so, then is this just another example of the profound mystery surrounding any attempt to understand the nature of quantum mechanics.

Notes

1. In all these experiments except Lamehi-Rachti & Mittig (1976), the system does not consist of two spin 1/2 particles, but instead two photons of correlated polarizations emitted in opposite directions. Polarization states in photons are the electromagnetic analogues to particle spin states.

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A Translation of a Zosimos' Text in an Arabic Alchemy Book

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ABSTRACT

In a recent paper (El Khadem 1995), it was reported that an Arabic translation of a Greek text by Zosimos was found in a copy of a book entitled "Keys of Mercy and Secrets of Wisdom," written by the twelveth century alchemist Al-Tughra'i. Reported here is a description of this rare book, which has recently been added to the Library of Congress' Near East Section collection.

Tughra'i, Author and Translator

The copy of "Keys of Mercy and Secrets of Wisdom" under consideration was written in two parts designated, "Part One, Introduction" by Al-Tughra'i", and Part Two, "From Keys of Wisdom by Zosimos" translated to Arabic by Al-Tughra'i. The author and translator's full name is Mu'ayed-ul-Din Abu Ismail Ibn Al-Hassan Ibn Ali Al-Tughra'i. He was born in 1062 A.D. in the city of Asbahan in Persia and was later appointed "Katib" (secretary) in the court of the Seljuq Sultan Malik-Shah and that of his successor, Sultan Muhammad. Because of his skills in calligraphy, he was assigned the duty of affixing the royal signature "Tughra" to the sultan's writs (hence his name, which means the writer of Tughras). After several years, Tughra'i moved to Mosul in Iraq where he was appointed Vizir to Emir Ghiyat-ul-Din Mas'ud. When the Emir died, uncertainty regarding his successor led to a palace revolt. Tughra'i sided with the oldest son, Mas'ud, who subsequently lost the power struggle to a younger brother, Mahmud. The latter, angered by his support of his brother,

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arranged to have him accused of heresy and then had him beheaded in the year 1121 A.D. Tughra'i's execution caused dismay among the learned community in the region and prompted many publishers to delete all what they considered controversial from his books.

Tughra'i was a statesman, an alchemist and a poet, considered by many as one of the key literary figures of his time (see Nicholson 1941). The present text, which according to an annotation on its title page, was also known as: "Key of Mercy and Lantern of Wisdom" and "Key of the Treasures and Lantern of the Symbol", has been cited by authors, such as Ullmann (1972), who lists it as "Keys of Mercy and Lanterns of Wisdom", and Sezgin (1971) and Kraus (1943) who list it as "Keys of Mercy". None of these authors, however, mentions that this, or any other book by Tughra'i, contains a translation of a text by Zosimos. A possible explanation of this absence is that the translation of Zosimos' text was deemed sufficiently controversial to delete it from many copies of "Keys of Mercy."

Zosimos:

Zosimos, the author of Part Two of the present text, was the most famous alchemist of his time. He was a gnostic philosopher, born in the city of Panopolis (present day Akhmim) in Southern Egypt around the year 300 A.D. He lived in Alexandria, and traveled to many parts of the Hellenic world (see Read 1937, and Hopkins 1967). Although Zosimos was a prolific writer, all his books have been lost and what remains of them today are mere passages and quotes written in the original Greek language, or translated to Syriac or Arabic. The Greek and Syriac texts have been translated to French by Berthelot (1885, 1888, 1893) and discussed in detail by Halleux (1979) and Mertens (1990).

Arabic translations of Zosimos' work are listed by Sezgin (1971, p. 73) and by Ullmann (1972, p. 160). They are also listed in the Arabic encyclopedia, "Kitab al-Fihrist", published in Baghdad in 987 A.D., by Ibn Al-Nadim (1872). In Section Ten of this book, Nadim gives the titles of four books authored by Zosimos (see Flugel 1872); they are: "Keys of the Craft," by "Rimos," (its title was translated by Berthelot 1888, p. 28) as "Keys of the Work"); "Keys of Magic," by "Thosimos"; "The Book of Elements," by "Dosimos" and "Book to All the Wise of the Craft" also by Dosimos. The inconsistency in spelling Zosimos' name can be traced to two reasons: (a) Arabic vowels may be deleted, altered, or transposed, according to certain rules, to render foreign names easier to pronounce; (b) the pairs of Arabic letters "Ra" and "Za" that produce the sounds "R" and "Z," and "Dal" and "Thal," that produce the sounds

''D,'' and ''Th'' (as in ''the'') are identical in shape, except for a dot on top of the second letter of each pair. A dot on the letter ''Ra'' changes it to ''Za'' and a dot on ''Dal,'' forms the letter ''Thal,'' In the writings of Geber, Avicenna and Tughra'i, Zosimos is referred to as Rismos or Zismos, depending on whether the copier of the manuscript remembered to put the dot. For example on p. 2 of the Introduction of the present text, Zosimos' name is spelled with a dot, whereas on the title page of Part Two it is spelled without the dot. Nadim, probably did not realize that the authors he lists as Rimos, Thosimos and Dosimos were one and the same person. Furthermore, because ''The Craft,'' ''The Work,'' and ''Magic,'' were synonyms used to describe ''Alchemy,'' it is quite possible that Zosimos' books listed as, ''Keys of the Craft,'' and ''Keys of Magic,'' were one and the same book which Tughra'i later referred to as ''Keys of Wisdom,'' because he did not wish to use of the word ''craft'' or ''magic'' lest he be accused of heresy. Nadim describes ''Keys of the Craft'' as a collection of letters, numbered one through seventy, and states that the book was also called the ''Seventy Letters.'' Another book having the word ''Keys,'' in its title namely, ''The Book of Keys,'' also known as ''The Little Key of Zosimos,'' is more difficult to relate to the present text, because it was not listed by Nadim; it was cited instead by the Byzantine monk, Michael Psellus (see Berthelot 1885).

The Text

The present book contains extremely valuable historical information about the chemical knowledge available in Tughra'i's time. Unfortunately, Part Two is not a verbatim translation of Zosimos' book ''Keys of the Craft,'' since it offers comments without specifying whether they belong to Tughra'i, or to Zosimos. It does however, give a detailed summary of Zosimos's text, and contains innumerable direct quotes of Zosimos and many philosophers of antiquity.

The Preface of ''Keys of Mercy and Secrets of Wisdom'' lists the chapters of both parts of the book. Part One or ''Introduction'' is divided into five chapters: I. The science, and its Materials; II. Mixing and its Ways; III. Fire and its Nature; IV. Balances (of properties); V. Metals and Plants and how to Recognize them. Part Two, entitled ''From Keys of Wisdom,'' is divided into seven sections: I. Definitions and Symbols; II. Promotion, and what can be Promoted; III. Distillation, what can and cannot be Distilled; IV. Conversions and Synthesis; V. Degradation and Decomposition; VI. How Chemists Deduced these Facts; VII. The stages of the Work. Even though the chapters of the two parts of the book have different titles, they are similar in content and present the subjects in roughly the same order. Two sections of Part Two, namely Section Five and Section Six

were missing from the copy studied. However, because their subject matter had been previously discussed in Chapters Four and five of the Introduction, it was possible to comprehend the text without much difficulty.

"Keys of Mercy and Secrets of Wisdom" is written in the format of lectures. The narrator in both parts of the book seems to be Tughra'i since he refers to Zosimos in the third person. Furthermore, Part Two often contains references to things that had not occurred, or did not exist in Zosimos' time. Example of these are statements like: "the Moslem philosophers said . . ." (Islam came three centuries after Zosimos' death), and "gun powder" (a product that was not known in Zosimos time). Similarly, in a dream depicting "Cinnabar," as a giant sitting on a throne reached by nine steps (the number of steps needed to prepare the elixir), the person relating the dream praises the prophet Mohammed, and invokes the archangel "Israfil" (the angel who blows the horn on judgment day, according to certain Islamic writings). In both parts of the text, the narrator ends each paragraph with the typically Islamic cliche: "God is more knowledgeable," which Zosimos, a Christian, would not normally say. However, it is also quite possible that these pious words were intentionally added by Tughra'i to abate criticism by the religious leaders of his time.

Although some might suspected that Zosimos' name was added to the book in order to enhance its value, this possibility is remote for two reasons: (a) Tughra'i was a successful author and an influential statesman, who did not need such a practice to promote one of his book, and (b) Zosimos' name is not displayed prominently, but seems instead to be intentionally hidden; it does not appear on the book's title page, but is relegated to the title page of Part Two, which comes after hundreds of pages belonging to Part One.

The Quotes

Among the many quotes attributed to Zosimos, some are in the form of letters addressed to women. One is addressed to a certain Maria (probably Mary the Copt), and stresses the importance of rigorously following procedures in any chemical work. Zosimos says: "You may think, Maria, that all the balances and the ten laws that pertain to the Substance (the elixir) need not be rigorously followed, and that some may be altered a little, while others may be totally ignored. It is not so; never disobey any of the rules, otherwise you will not succeed in your preparation and all your efforts will be wasted." In turn Mary asks: "Can you produce gold but from gold, or can you form a metal from a non-metal? Can you produce a man save from a man; a plant except from a plant and an animal but from its own kind?"

In another section of the book Zosimos is quoted as saying: ''Knowledge is treated with great honor, because only a philosopher, who has acquired Wisdom, scientifically and practically, is able to use it. An experimentalist may obey his master when he tells him: Take this and do such and such a thing, evaporate it, dissolve it, distill it, and so on till the end of the work. That aide does not understand anything beyond how to do things; whereas the person who comprehends the science and the practice, knows how and why something is evaporated, i.e. the purpose of the evaporation. This is why, to become a philosopher, one must know the aim of Wisdom in each step of the work.''

The book also contains several quotes made by famous Greek philosophers, such as Aristotle, whose discussions with Plato are reproduced in some detail, and Democritus, who is quoted as saying: ''The stone is not formed until it has gathered all the colors that exist in the universe, and until it has been colored with all the simple and complex colors.''

Galen is quoted as saying: ''To determine the amount of a drug to be used as an antidote, select three doses; one in great excess, let it be forty eight (48) units of weigh; drams, iotas, or any other unit; the second in the middle, which is twenty four (24), and the second (third), which is the least, six (6) parts. To determine which of these to use, consider all the variables, the powers, and the reasons, as well as the benefits gained by increasing the dose to forty eight units or decreasing it to six. If one condition requires an increase and one condition a decrease, then you use twenty four.''

The book also contains quotes from lesser known personalities such as Andromachus (a contemporary of Galen), Heracles, Tamagus and ''Balinas'' (Apollonios of Tyana). Also quoted, are mythical characters, such as Hermes Trismegistus, his son Tata, and his daughter Queen Cleopatra. For example, Hermes is quoted as saying: ''A body will not accept a soul that is not its own, and a soul will not reside in a body that is not its own. Thus a human body will not accept the soul of a bird, and the soul of a bird will not reside in a human body.'' Unfortunately, some Greek philosophers quoted could not be identified because of lack of records, or because transliteration had altered their names beyond recognition.

Among the Greek literature cited in Part Two of the text are: ''The Book of Revelation'' (Istigla') by Aristotle; ''The Basics'' by Apollonios of Tyana (Balinas), from which a passage is quoted, describing how to dye elixirs with yellow colors extracted from a sun flower like plant called in Greek ''Lumenia'', and ''Letters from Ostanes to Cleopatra'', which are discussed in some detail.

Content of the Book

Both parts of the book start with a discussion of the ''four elements'' (fire, air, water, and earth) and the ''four natures'' (hot, cold, moist, and dry), and

continue with their quantitative estimation. This is followed by a determination of their ratios and how to amend these to form the elixirs. The book ends with the use of the white elixir in the transmutation of copper to silver and the red elixir in the conversion of silver to gold.

Both parts of the book contain detailed accounts of dreams that reveal the secrets of Alchemy and long sections dealing with astrology and the role of the seven "planets" (the sun, the moon, Mercury, Venus, Mars, Jupiter, and Saturn) in each stage of the work. They abound with diagrams depicting benefic and malefic configurations of "planets" and their effect on the work.

Nomenclature is quite confusing because the chemical names bear no relation to composition. For example, lead sulfide is referred to as the "Tree that Grows in the Black Soil of India" because of its color and the heat used in its preparation from sulfur.

Most of the conclusions reached by the authors of the text are today invalid because of two major flaw in reasoning: The first is the belief that there are only four elements, and the second, that metals are not elements, but compounds. In spite of these shortcomings, Alchemists have succeeded in producing yellow colored alloys made of silver and gold, and white ones made of copper and silver. Avicenna (Ibn Sina) correctly warned his contemporaries that it was not possible to produce real gold chemically, saying: "Only imitations of gold can be formed, because the essential nature of a pure metal can never be altered" (see Holmyard 1928). His ideas were unfortunately disputed by Tughra'i in the book "Facts about Martyrdom." Zosimos believed in transmutation, but he correctly states that to prepare gold (alloys) out of silver one must start with gold, and to make silver out of copper one needs silver. He is quoted as saying: "He who sows silver reaps silver, and he who sows gold reaps gold." His mistake was to think that the amount of silver or gold added increases like that of yeast during fermentation.

Some of the important contributions of alchemists, discussed in the present text are the distinction between distillation, and pyrolysis (which they called smoking). Their success in making stills and constant temperature reactors, can be seen in the illustrations depicted: Thus Fig. 1 shows a sublimation apparatus; Fig. 2 the precursor of the modern Kugelrohr; Fig. 3. shows a reactor warmed with what is described as "moist heat", and Fig. 4. an incubator warmed by fermenting garbage and burning coal. In a remarkable statement, Zosimos explains why vapor rises against gravity during distillation; he says: "Motion is due to heat for without heat there would be no motion".

Most alchemists rejected the idea of "spontaneous creation". Thus Tughra'i says: "Try as they may the wise were never able to form something from something other than what it is normally generated from; humans from human semen;

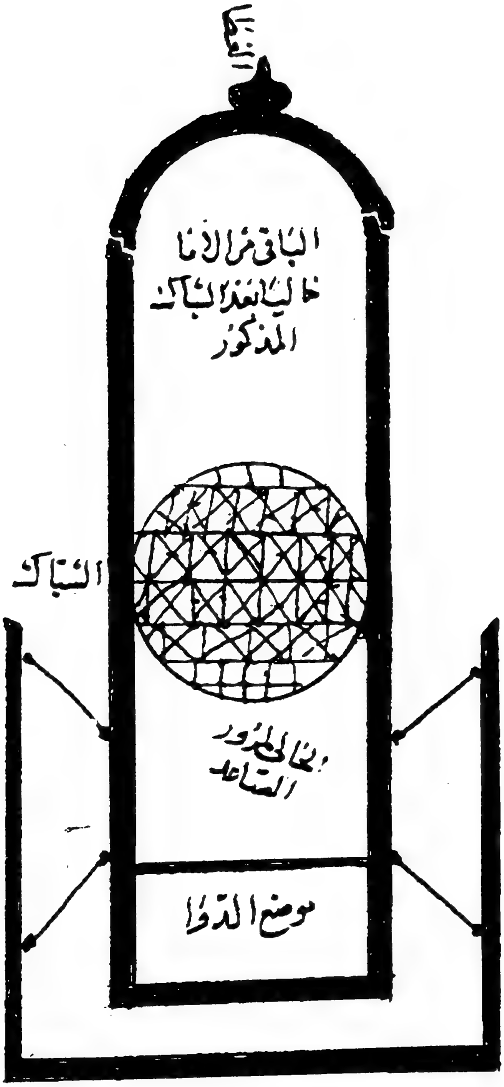

Fig. 1. Sublimation apparatus.

wheat from its grains, etc. They tried to produce snakes and asps by fermenting human hair; bees and wasps from putrefied horse meat; humans from human flesh as well as from innumerable other things, but they all failed.''

Format of the Book

The manuscript ''Keys of Mercy and Secrets of Wisdom'' is written in black and red inks; black ink for text, red ink for punctuation and both inks for art

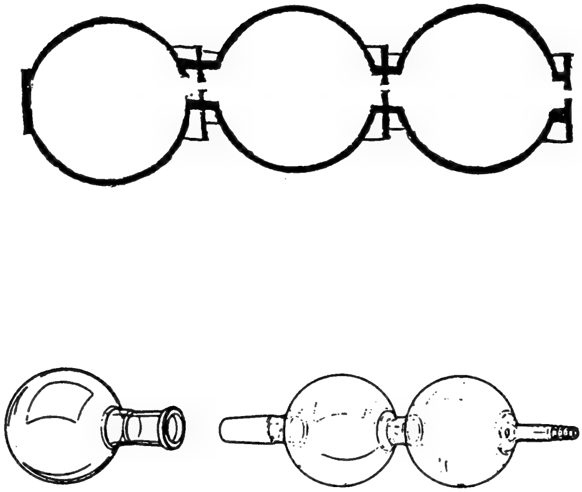

Fig. 2. Upper figure: A fractional distillation apparatus, made up of three glass flasks connected by metal and sealed with clay. Lower figure: a modern *Kugelrohr*.

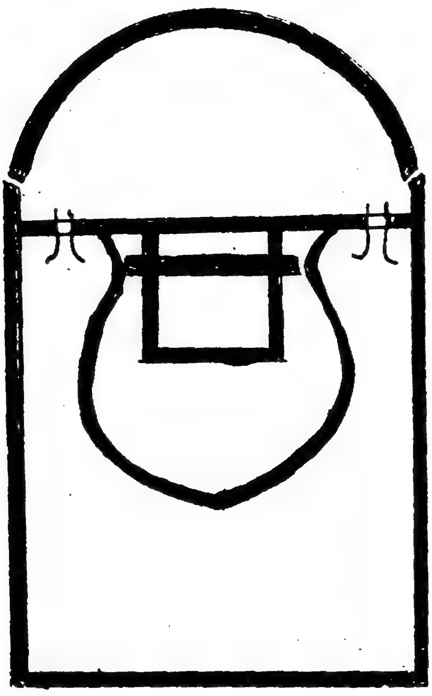

Fig. 3. Coal heated water bath to produce ''moist heat'' for a reactor.

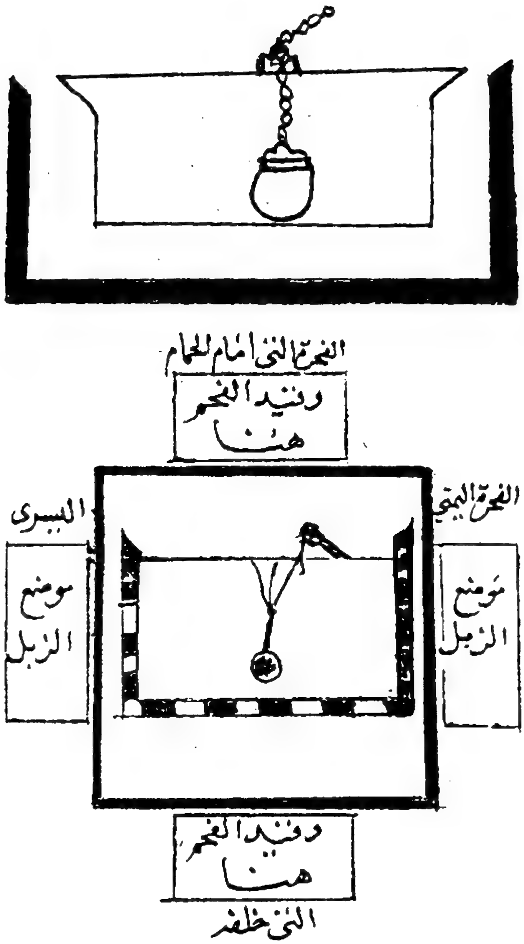

Fig. 4. Upper Figure: An incubation bath; Lower Figure: The bath placed in a pit warmed from two sides with fermenting garbage and from the other sides with coal.

work. The text was originally made up of 157 folios (314 sheets or 628 pages); of these 24 folios (48 sheets or 96 pages) of Part Two are missing. The Introduction, or Part One, is in 60 folios (120 sheets or 240 pages) grouped in 13 signatures (booklets), that contain 28 Tables and 23 Figures. Part Two is presently composed of 73 folios (146 sheets or 292 pages), arranged in 15 signatures, that contain 10 Tables and 42 Figures. Although the pages of the book are not numbered, it was possible to determine the existence of a gap, because the first word in each *verso* is entered at the bottom of the preceding *recto*. This made it possible to ascertain that there are missing pages between Sections Four and Seven. The size of the gap was determined from two annotations found at the end of each Part. These give the number of sheets that were present in the Part in question.

On the last page of Part Two, a recent owner of the book wrote: ''Owned by legal purchase by so and so, son of so and so, in the holy month of Zul-Que'da 1148 H. (1735 A.D.); 194 sheets in 19 booklets.'' A count of the actual number of sheets present in Part Two, revealed that 48 sheets (24 folios) in 4 booklets were missing. A similar annotation found at the end of Part One, revealed that this part contained 120 sheets in 13 booklets, which is the actual number of sheets presently found.

The pages of the book (204 × 147 mm) contain about twenty five lines of text (less if a page contains an art work). Tables and Figures are often surrounded by frames made of double red lines. The margins are generous; top margins are 24 mm, and bottom ones, slightly larger (26 mm). Side margins vary in width; the right margins in *rectos* and the left margins in *versos* are wider (60 mm) than the margins opposing them (18 mm). It seems that the two parts of the books were not kept separately because the last signature of Part One and the first of Part Two have identical worm holes and water stain marks.

Many of the side margins of the book bear annotations, written in ink by successive owners of the manuscript. An annotation on the title page states that the present text was also known by the two other names mentioned earlier, and lists the title of three other books by Tughra'i. They are: (a) ''Collection of Secrets and Compositions of Lights''; (b) ''Introduction to the Book of Healing,'' and (c) ''Facts about Martyrdom.'' There are also two biographical notes; one located on the title page, dealing with the biography of the author, and the other, on the last page of the book, which promotes the work of the fifteenth century alchemist, Al-Jildaqi, and names six of his books. In addition, there are several short notes in the margins, dealing with errors in the text and their corrections, and longer ones dealing with explanations and interpretations.

The present text must have been copied after Tughra'i's death, since his name is followed by the words ''May God have mercy on him.'' It is in a reasonably good condition, thanks to some restorative treatment administered in France after world war II. At that time the copy was dated, circa fifteenth century, which is consistent with the fact that the book was first published in the twelveth century, and has since then been periodically recopied. The restoration was made at the request of Dr. Puy-Haubert the war time Director of the French Hospital in Alexandria (Egypt). It involved cleaning the pages and spraying them with insecticides to kill the worms that had damaged the margins; then spraying the damaged pages with a varnish.

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Volume 84, Number 4, Page 179, December 1996

Obituary

T DALE STEWART, 96, physical anthropologist, died October 27 in Bethesda, MD. Born June 10, 1901 in Delta, PA, Stewart began a career association with the Smithsonian Institution in Washington, DC, in 1924 as an aide to physical anthropologist Aleš Hrdlička. He took premedicine courses at George Washington U (AB, 1927). After studying medicine at the Johns Hopkins U (MD, 1931), he returned to the Smithsonian, succeeding Hrdlička in 1942 as curator of the Division of Physical Anthropology. He served as head curator in 1961 and museum director (1962–66). Stewart formally retired from the Smithsonian in 1971 but continued professsional activity for another two decades.

Stewart taught at Washington U Medical School (1943), in Mexico City (1945), and at the George Washington U School of Medicine (1958–67). In 1954 and 1955, he assisted the US Army Quartermaster Corps in Japan in the identification of human remains recovered from the Korean conflict. This work led to the classic 1957 monograph (with Thomas McKern) *Skeletal Age Changes in Young American Males.* Additional research-related travel included work in East Africa, China, Guatemala, Iraq and Peru.

Stewart published over 200 articles and books, focusing mostly on interpretation of human skeletal remains but including topics in archaeology, forensic anthropology, history of anthropology, paleoanthropology (especially issues related to Shanidar Neanderthals), human and primate comparative anatomy, paleopathology, dental anthropology, general human skeletal biology and physical anthropology. His major works include *The People of America* (1970), *Essentials of Forensic Anthropology* (1979), the 1952 edition of Hrdlička's *Practical Anthropometry* and *Personal Identification in Mass Disasters* (1970). In 1992, at the age of 91 years, Stewart published a Smithsonian monograph on his 1938–40 archaeological work at the Virginia site of Patawomeke. Stewart is well known for his many problem-oriented articles, attention to detail, clarity of expression, meticulous scholarship and professional dedication. He was also an accomplished portrait artist who played the piano, loved to entertain and recount his world travels and always found time for students and friends.

For two decades beginning in 1942, Stewart served as the regular consultant in forensic anthropology for the FBI. In this capacity he reported on many cases and regularly testified in murder trials as an expert witness. Stewart was awarded an honorary doctorate degree from the U of Cuzco (1949). He received the Wenner-Gren Foundation's Viking Medal in Physical Anthropology (1953) and the Smithsonian's Joseph Henry Medal (1976). In 1962, he was elected to the National Academy of Sciences. He became an honorary member of the American Orthopaedic Association (1963) and the American Academy of Forensic Sciences (1974). Stewart served as president of the Anthropological Society of Washington, vice president of the Washington Academy of Sciences, president of the American Institute of Human Paleontology, member of the Committee on Research and Exploration of the National Geographic Society, editor (1952–48) of the *American Journal of Physical Anthropology* and president (1950–52) and treasurer-secretary (1960–64) of the American Association of Physical Anthropologists. In 1993, he received the Charles R Darwin Lifetime Achievement Award from the AAPA.

Stewart was preceded in death by first wife Julia Cable Wright Stewart (1951) and second wife Rita Frame Dewey Stewart (1996). He is survived by his daughter from his first marriage, Cornelia Stewart Gill, three grandchildren and 7 great-grandchildren. *(Anthropology Newsletter, Jan 1998)*

Journal of the Washington Academy of Sciences,
Volume 84, Number 4, Pages 180–183, December 1996

Annual Presidential Report
Washington Academy of Sciences

May 16, 1995

Naval Medical Center, Bethesda, Maryland

The most famous performer in the history of American musical theater was Al Jolson. One of Jolson's great attributes was his supreme chutzpah. The classic example came at a war-bonds benefit at the Metropolitan Opera House in New York City in 1917. Performing on the bill just before Jolson was Enrico Caruso, the greatest tenor in the history of opera at home in his own house. Caruso chose one of the supreme numbers for a tenor: *Vesti la giubba* from the opera *I Pagliacci.* The applause was thunderous. As it finally died down, Jolson ran on stage and sang out "You ain't heard nothing yet." From Caruso's own stage. No wonder the audiences loved him. (THE ECONOMIST, April 22, 1995, p. 88.)

Such is the state of American science at this moment as we look to the future. "You ain't heard nothing yet."

What do I mean? Let me give you an example.

A few years ago I was asked to deliver the centennial address at a little shrine in central New York State. Actually, it is the Shrine of the North American Martyrs in Auriesville, New York. The date was 1985. As I thought over the talk I did some research on how times had changed since the Shrine was originally dedicated in 1885. I found that the members of the original audience had arrived by one of three means of conveyance: river barge, horse and buggy, and passenger trains. As I looked out over the crowd in 1985 I was amazed to realize that not one of the guests in 1985 arrived by a means of conveyance that even existed in 1885. There are no more passenger barges on the Hudson for routine travel. The railroad station at the foot of the hill has been closed for years. Horse and buggies are rare and not one was there that day. No, everyone came in 1985 by car or bus, internal combustion driven gasoline fired vehicles. They did not even exist in 1885 except in Henry Ford's imagination.

If we now try to look forward to the bicentennial of that same shrine in 2085 the one point history tells us to hold for certain is that the audience will arrive by some means of conveyance that does not even exist at this time. We can guess

that such a prediction must be true. It is difficult to know with assurance when the supply of gasoline will finally run low on Earth but no optimist expects it to last till 2085. There will have to be a change. It is not clear what it will be.

You see, what is worrisome about the status of American science at this moment is something that the ancients already knew. Words can have opposite meanings. If I were to say, as Jolson did, that you ain't heard nothing yet from American science, I could mean that the future is rosy and resplendent, that the achievements of the past are only a hint of the wonders to be revealed in the coming century. The words could also mean, however, that the future would be bleaker than ever experienced before.

In ancient times this ambiguity of the future was classically expressed to the poor clients who came to the Delphic oracle for predictions of the future. Croesus, king of the Lydians, asked if he should attack his enemies. The oracle replied that he need have no fear, that, if he attacked, he would destroy a great empire. The point left vague by the oracle was whether it would be the enemies' empire or his own. Unfortunately for Croesus, it turned out to be his own.

We know how great our past has been. Just this year your Washington Academy of Sciences sponsored together with the Smithsonian Institution a lecture series featuring eight Nobel prize winners, all American. I am sure that our incoming President, Dr. John Toll, will mount an equally impressive program in the coming year that will bring us into contact with other scientists of equal stature. I am sure that you have all heard the wonderful news about Dr. Toll. He has been named President of Washington College in Chestertown, Maryland. That is wonderful news for Washington College to have so experienced an administrator, wonderful news for independent colleges in Maryland, and wonderful news for American higher education that needs strong leadership in our time of change.

But there are worrisome signs for our future. Consider the sad tragedy in Oklahoma City. What was the first reply? Of course, it was that one of the attorneys for O. J. Simpson, Johnnie L. Cochran, Jr., is now initiating a law suit against the makers of the fertilizers used in the bomb. The first reply was not to propose a law that the fertilizer, ammonium nitrate, be mixed with some harmless compounds of potassium and phosphorus that make the fertilizer unusable for explosives. That step has already been taken in Britain and Germany, as Russell Seitz of Harvard's Olin Institute remarked in an OP-ED piece in today's *New York Times.* No, we Americans reply by lodging a lawsuit.

The number of students majoring in the sciences is not encouraging. We can understand that fact. The future is obscure and it is difficult to know where the jobs will be. Industries are changing. Those related to armaments, for instance, are retrenching. Not fast enough, no doubt. The Bosnian factions seem to want to buy more armaments to an unlimited extent. They apparently experience a

monstrous perverse thrill in shooting women and children and none of their leaders has the courage of a Nelson Mendela to seek peace. But, still, jobs for scientists are problematic.

It is not easy to know the solution to that problem. One direction of wisdom seems to be to broaden the training scientists receive so that they have more flexibility in career choices. There are physicists who have studied no chemistry. There are biologists who have studied no mathematics. They say that there are even engineers who have studied no English. We do not want our students to close the doors to alternative options too soon.

Your Academy of Sciences has always been at work on this problem. One most evident sign is the magnificent achievement of Marylin Krupsaw with the Junior Academy of Sciences. Some of those youngsters may even succeed in solving that transportation problem for us.

As we look to the future with its uncertainties, we do always allow ourselves to be inspired and even in some sense directed by the past. Our own Academy is fast approaching its centennial in 1998. It is only right, therefore, that Dr. John Proctor, one of our past presidents, is chairing a major effort to celebrate our birthday. You will be hearing more about that program in the future.

One of the most troubling aspects to our future is a concern our friends in the Russian Academy of Sciences have explored with us already in our famous Georgetown University television program. But let me put it in a different context.

Last year I studied at the Max Planck Institute for Nuclear Physics in Heidelberg, Germany. In preparation for my remarks this evening I e-mailed a question to some of my friends there. ''What would you say to American scientists about science in the next century?'' One of the answers I got was startling.

Dr. Sandy Klevansky is a professor at Heidelberg University with which the Institute has close connections. She is from South Africa. She is just back from a return trip there. Much is going well in South Africa because of the excellent leadership Mandela and de Klerk have provided. If only we could clone those two. At the same time, it is a period of change. There is, for instance, a strong movement to overhaul the teaching of science so as to give equal time to ''traditional'' systems. That is, they want the teaching of Zulu science and witch doctor medicine in the curriculum of the universities.

The movement we call fundamentalism is world wide. Partially, it is healthy and necessary. We need a sense of values or we will all float rudderless in dangerous seas. But false and antiquated science, superstition and repression, we do not need. It is, however, there knocking at the door. It challenges us all constantly. I do think that American television has gone to absurd lengths, particularly in its daytime programming that is broadcast in a time slot so that young students coming back from junior and senior high school can see it. But is the

Iranian solution the way to go? Teheran has now outlawed the use of satellite disks because they receive American television and America, after all, is the great Satan. The desire to retain the traditional art and culture and identifications of ethnic groups is laudable but it can be murderous. Our Russian friends spoke of the problem in the abstract with us at Georgetown and then met it in the flesh in Chechnya. The desire to protect young people from the meretricious sensationalism of the worst elements of the entertainment industry is praiseworthy but takes a great deal of thought.

The moment at which we stand is a crossroads for science. We desperately need research and progress. The strange growls of the wild beasts off to either side of the road along which we are walking are thoroughly audible. We need only think of Aids and now the Ebola virus. Such monsters are moving stealthily through the grass around us. Only intelligence and wisdom are there to protect us. But with them we can make Al Jolson's cry be one of joy. As far as American science is concerned, you ain't heard nothing yet.

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The Washington Academy of Sciences: Background, Origin, and Early Years

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Introduction

As time proceeds, new organizations appear and old organizations disappear. Those groups which persist either fill a continuing need or adapt through time to meet new challenges. The Washington Academy of Sciences (WAS) of today is not the same as the organization of a century ago, yet its basic structure as a federation of Washington area scientific societies has remained substantially unchanged. A centennial is a particularly appropriate time to reflect on history, for considering where one has come from is one method of guiding movement into the future.

The background of the WAS stretches far back to the days of the Civil War in Washington and is linked to the growth and needs of the local scientific community for avenues of communication. During the last decade of the 19th Century, this growth reached a ''critical mass'' and a new form of organization appeared and evolved. One of the driving forces in this new structure was Charles Doolittle Walcott (Yochelson, 1967), president of the WAS for more than one-tenth of its existence and the one who led it into the 20th Century.

The National Academy of Sciences

Although a detailed study of the scientific societies in Washington has been published (Flack, 1975), a brief review with different emphasis may be appropriate. To begin, the National Academy of Sciences (NAS) was founded in 1863; it is emphatically not a local society, but plays a roll in this account. Although there were many underlying reasons for its formation, a pragmatic one was that

Charles Doolittle Walcott, second President of WAS. Photo Smithsonian Institution Archives, Record Unit 95. Negative No. 82-3143. Before the turn of century, Walcott wore a beard, as seen in his picture in the 25th anniversary history of the Cosmos Club.

the NAS did, in some small measure, enlist science in the cause of the Union. The most important founding member residing in Washington was Joseph Henry (1797–1878), the first Secretary of the Smithsonian Institution who became the second President of the National Academy from 1868 until his death.

The Academy met twice a year, with an annual meeting held each spring in Washington, and a fall meeting at whatever location would host the group. When Henry became the President of the NAS, he provided headquarters space for that organization in the Smithsonian Castle. What little day-to-day business there was came from that address until the NAS building was dedicated in 1924.

In an early effort to vitalize the NAS, Joseph Henry suggested that those members who resided in Washington meet once a month. Several NAS members from outside Washington, and especially Louis Agassiz, viewed this suggestion as a plot to place the NAS under the thumb of the Federal government; Henry tactfully withdrew his suggestion. Although the early records are murky, despite Agassiz' fuss, it is likely that this perceived need for intellectual stimulation and cross-fertilization led to the founding of the Philosophical Society of Washington (PSW) in 1871; the PSW included mostly non-members of the NAS.

During Henry's time, and for a few years thereafter, the PSW met at Ford's Theater, then the site of the Army Medical Museum. Science was serious business and Joseph Henry permitted no nonsense at the meetings. Joseph Henry also saw science as a broad-gauge activity. During the era that Henry was the principal scientist in Washington, no one would have dared to suggest that the approach of a scientific society should not be all-encompassing.

1879–1889

In the years following Henry's death in 1878, the number of scientific societies in Washington grew dramatically. Two prime factors in this growth were, first, the increasing specialization of various scientific disciplines and, second, the enlargement of the Federal government staff, especially in scientific activities associated with the Department of Interior, the Department of Agriculture, the United States National Museum, and the Fish Commission. A third key factor was the presence of the Cosmos Club in Washington, founded in 1878. Although this club was not by any means a formal scientific organization, it was an institution at which scientists rubbed elbows socially; when after a few years the Club finally settled on Lafayette Square, the assembly hall provided a centrally located meeting ground for the new scientific societies.

The first new scientific society to appear on the Washington scene, February 17, 1879, was the Anthropological Society of Washington. Its founding during

the winter of 1879 may have been pure coincidence, or it may have been a subtle form of lobbying for the Bureau of Ethnology. The bill which established the U.S. Geological Survey (USGS) on March 3, 1879, also established that Bureau. John Wesley Powell, one-armed explorer of the Colorado River, and the prime mover in founding the Cosmos Club, became head of the new Bureau and within two years was also director of the USGS.

The next scientific organization to be formed, on December 3, 1880, was the Biological Society of Washington. This was an organization near and dear to the heart of Spencer F. Baird (1823–1887), Second Secretary of the Smithsonian. Just as Henry had assisted the PSW in its early days and helped it start a bulletin, so Baird assisted the biologists.

The third scientific society to emerge was the Chemical Society, which began January 31, 1884. This group is considered the model and the ultimate starting point for the present-day American Chemical Society. One of the key persons in its formation was Frank Wigglesworth Clarke of the USGS, noted for his keen and biting wit. According to legend, one spring an out-of-town member of the NAS attending the annual meeting met him on the street and asked "How's the Comical Society?" Clarke reply was "Fine. How's the Notional Academy?" Apparently this was so upsetting to the academician that for some years thereafter Clarke was not elected a member of the NAS.

Four years after the start of the BSW, the National Geographic Society (NGS) appeared January 27, 1888. Despite its grand name, for the first few years of its existence the NGS was essentially a local body, though one designed to appeal more to the interested layman than to the professional scientist. It is interesting that this society was founded at just about the same time the USGS was endeavoring to increase its annual appropriation so as to produce more topographic maps.

The Joint Commission

Public lectures sponsored by the Smithsonian Institution which were an early innovation of Joseph Henry, actually started before construction began on the "Castle." The great fire of 1865 destroyed the lecture hall in that building, but completion of the United States National Museum building in 1881 (now the red brick Arts & Industries Building to the east of the "Castle") infused new life into that public program. During the spring of 1882, the Anthropological and Biological societies cooperated in organizing a lecture series on Saturdays. Although the PSW stood aloof for a few years, it became involved as another sponsor during the 1885 and 1886 lecture seasons.

Frank Wigglesworth Clarke, third President of the WAS. Smithsonian Institution Archives, Record Unit 7099. Negative No. 97-1692.

According to Gilbert (1899:2–4), the first secretary of the WAS, the three societies had a joint committee of conference in 1882, which recommended a federation of the societies into a Washington Academy of Sciences. This plan

Grove Karl Gilbert, first Secretary of WAS, Photo, Smithsonian Institution Archives, Record Unit 95. Negative No. 78-15934.

failed because the membership of the PSW voted against the proposal. As noted, inside of a few years that society did assist with the lecture series. There are no records, but it is likely that these arrangements for lectures laid the foundation for the Joint Commission (JC).

All Gilbert (1899:4–5) wrote of the formation of the JC was that ''Early in the year 1888 the desire for federation which had inspired the attempt to organize an Academy, led to the movement to secure a permanent committee to deal with the questions of common interest, and this movement was successful.'' Inasmuch as John Wesley Powell was one of the founders of the National Geographic Society and the JC suddenly appeared a month after NGS was founded, Powell may have been the proponent of this commission; he was a member of all five of the cooperating societies which originally formed the JC.

Many members of the Washington scientific community had eclectic interests and belonged to more than one of these new societies. The founding of The National Geographic Society could well have been the final straw in emphasizing the need for some sort of more general cooperation and regulation, even if Powell himself was not the driving force. Thus, February 25, 1888, the JC came into being to represent the five local societies. ''The Commission consists of three delegates from each of the component societies and its functions are advisory, except that it may execute instructions on general subjects and in special cases from two or more of the societies participating''.[1]

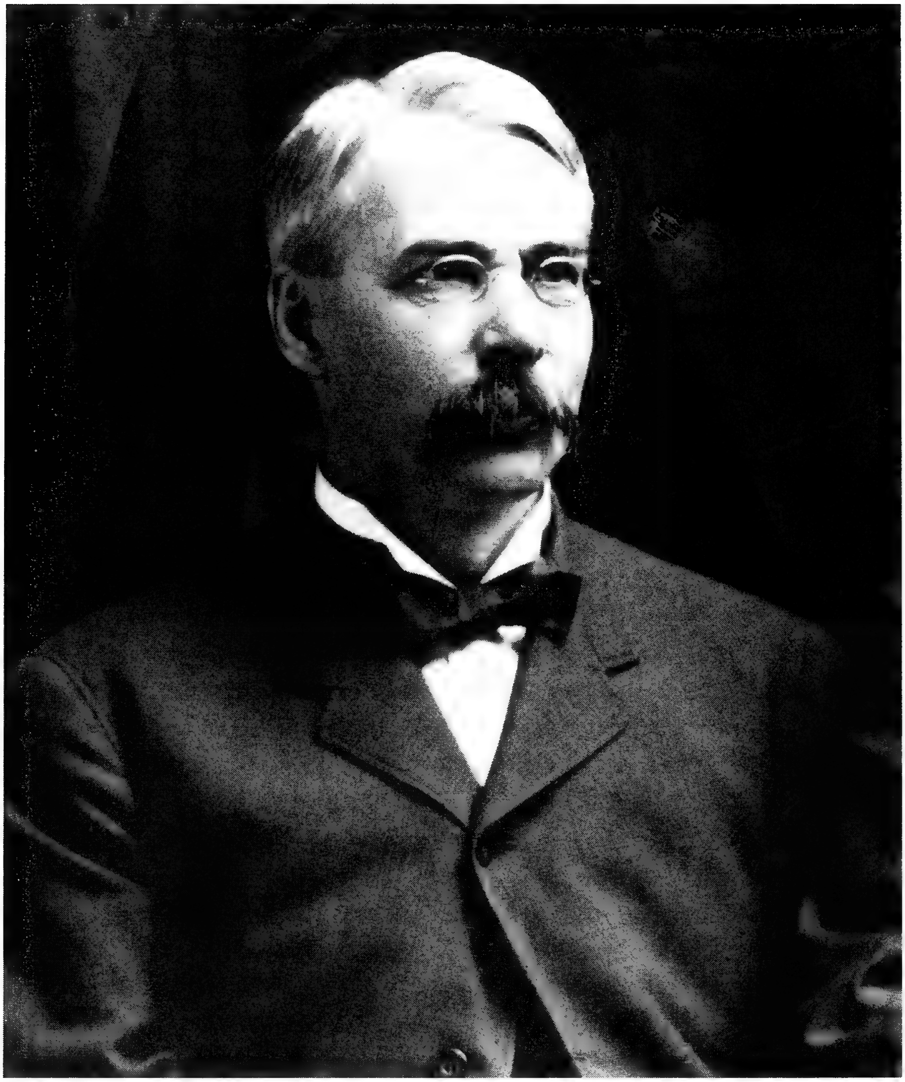
As an example of multiple memberships, in the first edition of the JC directory of the local societies Walcott is listed as a member of the Anthropological, Biological, National Geographic, and Philosophical Societies. The second year he had dropped out of the Anthropological Society and in the 1894 edition, naturally enough, he had added the new Geological Society of Washington to his membership.

Garrick Mallory, one of the founders of the Anthropological Society was the first president of the JC and Marcus Baker was the first secretary. Within a year, the JC arranged a calendar so that the several societies did not directly conflict on meeting dates. This calendar was published in the annual directory of members of the various societies. The introductory part of the directory gives a brief account of the JC and each of the five societies, along with the officers of each group.

The directory itself is a useful source of local addresses, work affiliation, names in full, and memberships; the directory also listed the non-resident members of these various groups. Its increase in size over the years documents the growth of the local scientific community and of the several societies. The 1889 edition listed 579 members, the 1890 edition, 662, and 1891, 851. In the fourth edition of 1892, separate counts were made for members in Washington and vicinity (684) and non-resident members (278) of the local societies.

In addition to the directory, one of the first actions of the JC was to invite the American Association for the Advancement of Science (AAAS) to meet in Washington in 1891. The AAAS had only met once previously in Washington and that was in 1854. Hosting this meeting was a formidable undertaking, but the JC was able to bring it off successfully. The newly formed Geological Society of America met in conjunction with the AAAS and immediately following it, the Fifth International Congress of Geologists convened, so the arrangements also had an international flavor.

The JC was a remarkably stable body during its early years with Mallory and Baker continuing in office for years. Delegates from the societies changed, but mainly it was by a member shifting from representing one society to representing



Marcus Baker, second editor of the *Proceedings*. USGS photographic library, Denver, Colorado. Negative No. 23 "Portraits."

another. On December 20, 1892, the Entomological Society was admitted to the Commission with one delegate, and on December 9, 1893, the Geological Society of Washington (GSW) was admitted with two delegates. President of the GSW Charles Doolittle Walcott appointed himself and J. S. Diller, another USGS employee, as the representatives to the JC. The founding of the GSW so late relative to the other disciplinary societies has been discussed (Yochelson *in* Robertson, 1993). There is no obvious reason for that delay, but the society itself came into

being within a week, during a respite from Congressional inquiry of the USGS which had begun in 1892.

The milestone of breaking 1000 memberships was reached in 1894 when 1072 members were listed in the Washington area; non-resident members of societies dropped to 140. More significantly, the JC underwent a major change. On January 25, 1895, the JC adopted a constitution written by J. S. Diller.[2] The officers and boards of the several societies formed the JC and it was given the power to organize joint meetings, arrange public lectures, and distribute notices of meeting, along with the publication of the annual directory. Walcott was one of seven members of the Executive Committee, one from each of the adherent societies, plus the two officers. Gardiner Greene Hubbard, president of the National Geographic Society, was elected president of the more formalized JC for several years and led it, or misled it, through the steps of this reorganization and the early phases of formation of the WAS.

It is not obvious as to what caused this change to a more formal structure. One possible factor may have been the action of the Women's Anthropological Society. The group applied for membership in the JC. The male worthies determined that the JC had no power to admit them and that only by an affirmative vote of all the affiliated societies could another group be included within the JC structure. As might be expected, the membership application failed, but it could have left in its wake a notion that having a set of rules to refer to might be appropriate.

The following year, the short constitution was reprinted in the directory along with bylaws and a list of 82 officers of societies who now became part of the JC, besides the 11 persons who were officers or on the executive committee.[3] This made for what was potentially a most unwieldy group.

The Geike Affair

To backtrack a little, Professor George Huntington Williams the founder of the Department of Geology at The Johns Hopkins University in Baltimore, died unexpectedly in 1894. He was a rising star in the study of metamorphic rocks and his death at 38 from typhoid fever was a tragic loss. Mrs. Williams instituted a lectureship to commemorate his memory and the first lecturer chosen for the honor was Sir Archibald Geike, director-general of the Geological Survey of Great Britain and Ireland and an expert on ancient volcanoes (Pettijohn, 1988:21).

At some time during the early part of 1896, Gardiner Greene Hubbard, then president of the JC wrote to Geike, inviting him to address the JC at Washington; Hubbard knew that this distinguished foreigner would be close by and this was

too good an opportunity to miss. Geike's reply, late in June was positive. "It will give me pleasure to accept your invitation to address the Joint Commission. . ."[4]

In May, 1896, before any reply had been received from Sir Archibald, Hubbard informed the GSW by letter that he had invited that worthy to Washington the following year, after Geike had completed his duties in Baltimore. Hubbard also asked the GSW to second his invitation.[5] However, GWS president S. F. Emmons then wrote inviting Geike to lecture before that society. When that letter was sent is not clear, but what was apparently another letter was sent to him on December 1, 1896.

On January 8, 1897, Geike finally responded to Emmons: "Your letter on behalf of the Geological Society of Washington gave me great pleasure. I have delayed replying in the hope of being able to say something definite as to dates. But this I find impossible at present. . . . I shall of course be very pleased to meet the members of the Society over which you so worthily preside. As for an address my hands are so full of work that I dare not promise any forward prepared discourse.[6]

According to a Washington myth, the JC invited Geike, but upon hearing of the invitation from the GSW, the JC withdrew their invitation. The geologists considered this a slight against a distinguished visitor and were incensed. As with so many myths, the real story is not quite that simple.

As early as December, 1896, the Chemical Society had informed the GSW of its concerns over the expenditures and functions of the JC. In mid-January, 1897, after Geike's somewhat vague acceptance of their invitation was presented to the GSW council and a committee on arrangements for his lecture appointed, the feisty council voted that a committee be appointed to investigate the history of the JC; Whitman Cross and G. K. Gilbert, both USGS, were appointed. Several times the committee reported no progress in gathering the necessary information, which certainly poured a little gasoline on the fire.

On March 18, 1897, Sir Archibald, who was becoming increasing cramped for time, wrote Hubbard: "I find that I can be in Washington from the 2nd to the 7th May and should be pleased if any date within these limits would suit the convenience of the Members [presumably of the Joint Commission]. The Geological Society of Washington has also asked me to address its members. I presume that they are also members of the Joint Commission and in that case it might perhaps suffice to have a single lecture".[7]

Geike further asked Hubbard to discuss matters with the president of the GSW and the same day sent another letter to Emmons, whom he thought was still president. "I don't know about a formal discourse that would be possible for me, my time for preparation being limited. But I would gladly address the Society

on some subject on common interest to us all. Mr. Hubbard asked me to address the Joint Commission and I am writing to him this much [?] for the subject. I hope it can be arranged that one lecture will suffice and perhaps you would kindly see him on this point''.[8]

A third letter on apparently that same day went to Hague, who as new president of GSW had re-extended the invitation. Part of Geike's reply was: ''You suggest the repetition of one of the Johns Hopkins lectures. I am quite willing to make that arrangement if you think it best or this address may be merely informal and be left to be decided on when I get to Baltimore''.[9]

These letters, innocuous in themselves—after all Sir Archibald had his hands full in Baltimore and Washington was simply an extra chore—added gunpowder to the explosive mixture of concern about activities of the JC. On April 1, 1897, possibly an appropriate date for this concatenation, the council of GSW voted almost unanimously that their society should sponsor the Geike lecture, but it was also agreed that they should consult with the JC.

At the JC Executive Committee meeting of April 6, 1897, President Hubbard noted that indeed he had corresponded with Sir Archibald, as had later the GSW. Near the end of the correspondence, Sir Archibald had indicated that he preferred to give a single lecture in Washington. At this point, the JC insisted that since Hubbard had written first, the JC was the appropriate sponsor of the lecture.[10] This opinion of the JC was technically correct, but it poured burning naptha on already troubled waters.

At the April 1, special meeting, the GSW council had appointed Walcott and its current president Arnold Hague to take up the matter with the JC. In two weeks, they reported that all had been smoothed over. Just incidentally, because of the press of other duties, Walcott had resigned from the GSW council in January and had no part, officially, in the specific and more general concerns raised by the GSW as to JC activities and the invitation to Sir Archibald.

Geike spoke on the evening of May 5, 1897, under the auspices of the GSW. The lecture went well, but it did not heal the strained relations between the JC and the GSW. The Treasurer had no objections to the bill of $7.00 for the lantern slides used, though earlier he had objected to what he considered excessive charges by the JC and insisted on itemized bills.

It took almost three months for the two-man investigating committee to gather the information on the JC which the GSW council had requested. When they were ready to report, the report was delayed until after the Geike lecture. A special council meeting was called on May 26, 1897, to discuss the JC. The council voted to send the report and a circular letter to all the other societies affiliated with the JC. The sentiment was that the GSW ''council expresses it disapproval of the present organization of the Joint Commission as being neither

well adapted for performing the business of the societies nor representing them in scientific matters''.[11] One concluded that the GSW was not happy.

The First Step

Whether the trigger was Geike's lecture, or that was simply the last part of a deeper concern, on September 15, 1897, the circular was distributed by the GSW; it suggested ''that the question of a joint organization should be considered by the scientific societies with a view to improving the means for furthering their common interests.'' The letter proposed that each society appoint ''a committee of conference to meet similar committees from other societies for the consideration of the general subject.'' These quotations are from the report of geologist G. K. Gilbert (1899:7), first secretary of the WAS and one-half of the GSW investigating committee; more details of this circular can be found in the GSW minutes.

Gilbert gave a brief summary of the history of the JC and in it noted two ''political'' actions undertaken in 1896–1897 by the reorganized JC. One was to endorse the request of the Secretary of Agriculture to Congress for a position of Director-in-chief of Scientific Bureaus and Investigations, and the second was to oppose a bill restricting vivisection in the District of Columbia. ''While the motives . . . were shared by nearly all members of the Commission, there was serious doubt as to the propriety of permitting a Commission organized primarily for business purposes to attempt to represent . . .'' This is a correct view of the sequence of events and was a good official reason to replace the JC structure; Gilbert was too much of a gentleman to mention the Geike problem, nor to note how unwieldy the JC had become.

Organizing for WAS

In the fall of 1897, as requested by the GSW, the seven local societies each appointed three people to the conference committee. The circular of the GSW, the conference committee members, and their final action were noted in *Science* (Anonymous, 1898). After several quick meetings, the group passed six resolutions, the fifth being the prime point. That one suggested changing the name of the Joint Commission to the Washington Academy of Sciences, that the WAS assume independent scientific functions, and that it have the power to add members. The resolutions were then sent to the JC and moved on to the affiliated societies for consideration. In short order, the Biological, Entomological, National Geographic, Geological and Philosophical societies accepted all six resolutions;

the Anthropological Society accepted the key resolution, and the Chemical Society had not met to consider the matter.

In the midst of assembling WAS, Gardiner Greene Hubbard died on December 11, 1897 at age 75. In addition to other activities, Mr. Hubbard was a Regent of the Smithsonian Institution and, though he was professionally a lawyer, he was a respected senior member of the inner workings of the city's scientific community; no one held him personally responsible for the confusion about the sponsorship of the Geike lecture.

By January 11, 1898, the Joint Commission began serious discussion on what had been started. Major Powell wanted a selected body which was financially stable. ''Mr. Gilbert spoke of the *functions* of the Academy expressing the belief that (1) it should not duplicate the work of existing societies but should seek to do what they did not do (2) that it should provide for courses of public lectures and (3) that provision should be made for *patrons*''.[12]

A committee of eight was appointed by the Joint Committee to draft a constitution, and they immediately added seven members including Walcott. Interestingly enough, he did not attend the first four meetings of the constitution committee. He had other business to occupy himself, with a new session of Congress starting, but he must have been kept apprised of the discussions.

Enter Walcott

This heading is an oxymoron, for though Walcott was not officially involved until January 19, 1898, as one of the vice-presidents of the JC, he for years had had his finger on the pulse of Washington science. In addition to being director of the Geological Survey, late in January of 1897 he took on the additional task of Acting Assistant Secretary of the Smithsonian Institution in charge of the United States National Museum, a position he held for eighteen months. Hardly had he agreed to that, when suddenly from late February onward he was heavily involved in the setting up of the National Forest Reserves and when the smoke cleared in the spring of 1897, the USGS was studying trees, as well as rocks and water. This was also the year he was vice-president of the Cosmos Club; the following year he was president.

It was on that January night in 1898 that the JC authorized the Committee on Constitution to incorporate WAS under the laws of the District of Columbia. The constitution was distributed to the affiliated societies. On the evening of January 25, 1898, the JC had two main pieces of business. The Medical Society of the District of Columbia had asked to be admitted to the JC; it was agreed that while this was an appropriate society to include within the fold of the JC, no action

should be taken until the WAS was formed. Then came the more difficult issue of who should be in the WAS. Several plans had been circulated, other ideas were proposed by the affiliated societies and still others came from those present.

"Mr. Walcott then offered a substitute for Dr. Merriam's motion which after discussion was adopted in the following form:

Resolved That a nucleus of 75 members of the Washington Academy of Science be formed by election in the following manner:

Each member of the Joint Commission may prepare a ballot containing not more than 100 names of persons now members of one or more of the scientific societies of Washington, the ballot to be canvassed by the Executive Committee of the Commission not later than Monday Jan. 31, and the 75 persons having the largest number of votes to constitute the original members of the Academy".[13]

The Executive Committee was given the power to decide on a member in the event of a tie vote. Other suggested changes in the Constitution were referred to the fifth and final meeting of the Committee on Constitution, six days later. General Sternberg, Surgeon-General of the Army and the new president of the JC, had a previous engagement and Walcott was asked to chair this late afternoon meeting; he had helped write the constitution for the Geological Society of Washington and earlier had helped to revise the constitution of the Biological Society. That same night the Executive Committee of the JC met from 8:00 PM until 2:00 AM to determine the 75 members. The individuals selected received from 18 to 32 votes each and, as Walcott had anticipated, there was a tie for the 75th place.

February 2, the Executive Committee of the JC met again. This time the main agenda items were fine tuning of the constitution and a reading of the proposed articles of incorporation. Then the document was turned over to the several societies for their consideration. The established PSW was as reserved as the new GSW was feisty. Fortunately Walcott was a vice-president of the PSW and at a meeting two days later, he "Voted to support Washington Academy of Sciences",[14] which was hardly a surprise. In its vote the PSW reserved the right to consider the final product, a formality which soothed the concerns of a few members of that august group. In founding the WAS, the aligning of the PSW was by all odds the most formidable task of salesmanship.

February 18, 1898, the members of the Constitution Committee met to incorporate the WAS, not forever but for a term of nine hundred ninety-nine years. They met again on March 5, to give legal status to the elected officers of the new organization. March 22, the JC held its last minute and adjourned *sine die*. In accordance with Murphy's Law, the early part of the meeting was marked by an argument that a quorum was not present; fortunately, several members appeared late and completed the transition from Joint Commission to Washington Academy

of Science. The functions of the new WAS and its officers were again an item for ''Science'' magazine, (Anonymous, 1898a).

The archives of the JC went to the WAS and their furniture was donated to the Cosmos Club. In a bizarre sort of justice, the JC archives do not contain the final resolution dissolving itself, but a copy is pasted in the minutes book of the GSW.

1898

Unfortunately, the early minutes of the WAS are lost. Gilbert (1899:xii) records only five items for the first year. The first two are the incorporation and organization meetings mentioned above. A second and third meeting for organization were held on March 17, and March 29, respectively. Finally, a business meeting was held for election of members on May 27.

However, more was happening: ''The Board of Managers has held numerous meeting for the transaction of business.'' The Medical Society was admitted; its president gave his address under the auspices of the WAS, as had the president of the Anthropological Society earlier in the year. It may be noted that J. R. Eastman, of the U.S. Naval Observatory, was the first President of WAS, G. K. Gilbert, USGS, was the first Secretary, and Bernard R. Green, Superintendent of Construction, Library of Congress, was Treasurer. These officers, and nine vice-presidents representing each of the affiliated societies, supplemented by the elected Board of Managers, were to manage the WAS.

''The principal work of the Academy in 1898 was organization. . . . A number of business meetings were held by the Academy and the Board of Managers in the spring, and the Board of Managers held another series of meetings in the autumn and winter . . . the Board has developed the machinery for the publication of proceedings, the conduct of a lecture course, and the holding of occasional meetings for the reception of new scientific material. The function which has received the most attention is publication. A plan for the selection and printing of papers has been carefully matured and accepted papers will soon go to press. A joint directory for 1899 is now in preparation under the editorship of Mr. Marcus Baker. [Issued February 24, 1899]'' (Gilbert, 1899:13–14).

The constitution as first written made provisions for three classes of membership, patrons, honorary members, and regular members. In addition to the 75 members first elected, another group was added in mid-March, and later a number more, mainly as a result of the Medical Society affiliating with the WAS. A few persons declined membership, a few others did not pay dues, and when all was settled, the WAS had 147 ''original'' members. These paid dues of $5.00 and were to receive the *Proceedings.*

James R. Eastman, first President of WAS. Photo, Smithsonian Institution Archives, Record Unit 7099, box 32. Negative No. 97-1690.

That spring, in an amendment to the constitution, non-resident members were added as a category. Dr. Florence Bascom, Professor of Geology at Bryn Mawr was elected a non-resident member of WAS in 1905. In 1906, the category of life member was added to the constitution, the requirement being a payment of $100. A 1907 letter addressed to ''Miss Florence Bascom'' stated: ''Dear Madame, I have the honor to inform you that at its meeting of January 8, 1907, the Board of Managers elected you a life member of the Washington Academy of Sciences''.[15] For years, thereafter she was indicated on the membership lists as a life member; for at least the first few decades of the WAS she was the only life member and may have been unique in that category.

Bernard R. Green, first Treasurer of WAS. Photo Library of Congress.

The same year that the first life member was elected, the first honorary member was also elected. The published minutes do not give the names of either. Who was the first honorary member is a minor mystery for someone else to pursue.

In the separate membership lists of the WAS, produced in later years, honorary members were named, but there are no dates of election nor any clue in the WAS minutes as to the process.

Regardless of what plans the WAS might have had, money was vital to finance the directory and, more importantly, to the start of the *Proceedings.* The JC noted a donation from Mrs. Gardiner G. Hubbard in memory of her husband, and in 1899 she made another donation to the WAS. The list of resident members published in the first volume of the *Proceedings* lists her as a patron, the first one. Patrons contributed $1000 or the equivalent in property to the WAS.

The WAS Directories

The housekeeping chores, if you will, of the Joint Commission were carried on by the Washington Academy of Sciences. The directory with the calendar of meeting was an important document. ''This Directory, like that for 1899, 1900, and 1901 (none was published in 1902) has been prepared and published under the direction and at the cost of the Washington Academy of Sciences. It [the Directory] may be regarded as the successor to the Joint Directory of the Scientific Societies of Washington, which first appeared in 1889, and annually thereafter until 1898''.[16]

Late in 1901, the WAS issued a form to all members asking for details which might be included in the next issue of the directory.[17] Most members complied with the request.

In 1903 and thereafter for the next two decades, the directory was issued biannually; the directory continued into the 1940s. Those issues produced during Walcott's tenure as president are listed in the notes.[18]

Proceedings, Patrons, Members

Volume 1 of the *Proceedings of the Washington Academy of Sciences* bears a title page date of 1899; (the volume was not completed until 1890). Volumes 2–4 were yearly, but 5–9, each crossed into a succeeding year. Volumes 10–13 were each within the year 1908–1911, respectively. Officers of WAS are listed and in all volumes save the last, the president is Charles D. Walcott.

The *Proceedings* actually say little about the activities and meetings of the WAS, but serve as a vehicle for publication of papers. The manuscripts accepted by the publication committee could come either from the WAS or be forwarded by any of the affiliated societies; the societies were expected to contribute half the cost of publishing manuscripts originating within their society. Publication

WASHINGTON ACADEMY OF SCIENCES.

NOVEMBER 5, 1901.

DEAR SIR:

The Publication Committee of the Academy has been directed to prepare a new list of members for insertion in the current volume of PROCEEDINGS. To this end, members are requested to fill out the following blank and return promptly to

MARCUS BAKER,

1905 16TH ST., WASHINGTON, D. C.

[Name. *Name is preferred in full.*]

Charles Doolittle Walcott.

[Academic degrees, with institutions conferring them.]

LL.D. - Hamilton College.

LL.D. University of Chicago.

[Please state if editor of any scientific journal, or member of other societies. *Give only a few leading societies.*]

Treas. Natl. Acad of Sciences, A.A.A.S

Pres. G.S.A.; Pres. Phil. Soc. Wash.

[Official position or title if any]

Director, U.S. Geological Survey

[Official or business address. *Give also any special address.*]

U.S. Geological Survey Office

Washington, D.C.

Information form of Charles Doolittle Walcott for WAS Directory

was quarterly in brochures which contained one or more papers; each separate paper within a brochure also appeared as a reprint and was available for sale. Membership of the Publication Committee and the rules concerning publication are given in the *Proceedings.*[19]

Walcott (1900) availed himself of this series twice. The first article is based on field work conducted in eastern Canada during 1899. He did not return to Washington until mid-September and was unable to start on the manuscript until early December, yet it appeared February 14, 1900; as shown below, his speed in writing matched that in setting up organizations. This paper completed the volume I of the *Proceedings.* His article is profusely illustrated and in some respects resembles articles of that day in the ''National Geographic Magazine;'' it cost $.50. Some years later (Walcott, 1905), he published a much shorter article, which sold for $.10. The proceedings of the commemorative meeting to John Wesley Powell at which Walcott presided cost $0.75.

One outgoing letter in 1901 indicates that non-members of the WAS could purchase an unbound volume for $5.00.[20] A copy bound in red cost another 50 cents for non-members; members received bound copies. The same letter suggests that an exchange program with other societies was in operation. What happened to any publications received in exchange is another minor unsolved mystery.

Critical to any publishing enterprise is money, for if one does not pay the printer, there is no printing; as generous as Mrs. Hubbard had been as the first patron in 1899, more support was needed. On January 12, 1901, the Council of the WAS unanimously voted two more persons to patron status, James W. Pinchot of New York, and his son Gifford Pinchot, by then nominally an employee of the Department of Agriculture[21]; each donated $1000 to the WAS. There are no hints in Walcott's diary as to how this came about, but if Gifford Pinchot had one stalwart supporter in Washington it was Walcott. In 1896 Walcott provided office space for the NAS Forestry Commission and later managed to obtain the essentially honorary position for Pinchot as a forester in Agriculture. He arranged for Pinchot to speak to the NAS and even tried to have him elected to membership in the Academy. None of this information proves Walcott asked for the financial support, but it is otherwise inexplicable why the elder Pinchot would support a local Washington society.

The younger Pinchot, never one to make life easier for anyone, complained that with Patron status he was no longer eligible to vote and the rules committee struggled to resolve this problem. Eventually he was permitted to exercise his franchise without payment of annual dues. On the annual summary of total membership, there is a category of ''counted twice'' containing the figure 1; that is Mr. Pinchot, member and patron.

The timing of notifying these two patrons is a bit strange in that the title page

of volume 2 of the *Proceedings* is dated March-December, 1900; likely, the prefatory material was printed and mailed early in 1901. Preceding the list of members are the names of five patrons (Anonymous, 1900: xii).

The remaining two patrons listed in that first volume were also elected in 1900, though no letters give the date of elections or any details. One of the patrons is Thomas Walch. He began by grubstaking miners in the west and ended up owning a gold mine in Ouray, Colorado. After achieving monied status, he moved to Washington; his mansion on Massachusetts Avenue is now the Indonesian embassy. Walcott could have talked both mining and Washington real estate with him.

Walch is followed on the list of patrons by Mrs. Henry L. Higginson. Mr. Higginson was a friend of Henry Adams and in 1902 was a member of the Board of Trustees of the Carnegie Institution of Washington; he died almost as soon as the organization was founded. Adams was a friend of Walcott. Bizarre though it may have been for the senior Pinchot in New York to support WAS, it is even stranger that this lady from Boston should be involved, yet it is the sort of arrangement that Walcott would have engineered.

In May, 1901, E. H. Harriman, the railroad magnate in New York became a patron. In 1899, he financed an elaborate expedition to Alaska and before it departed, Walcott and C. Hart Merriam of the Biological Survey went to visit him. In later years, Walcott had frequent contact with Harriman; Walcott held a patent on a railroad tie spike and promoted it for years. A few years later, a number of shorter papers resulting from the Harriman Alaskan Expedition were published in the *Proceedings.*

On Friday, December 13, 1901, Walcott ''Called on Mr. Cleveland H. Perkins & talked to him of Washn. Acad. Sci. He agreed to send $1000 to aid in publication''.[22] Walcott must have been a silver-tongued orator, for he did not know the man; he later wrote the surnames of Mr. Cleveland in his diary and got them backwards.

At some time during that same year Mrs. Phoebe A. Hearst, of San Francisco, California, was added to the list of patrons. She was the wife of Senator George Hearst and a philanthropist in Washington. Thus, the fourth volume of the *Proceedings* lists eight patrons. Apart from Mr. Perkins, there is no proof that Walcott obtained their support, but he is a likely source for all these patrons. However their support may have been gained, the WAS was now financially stable.

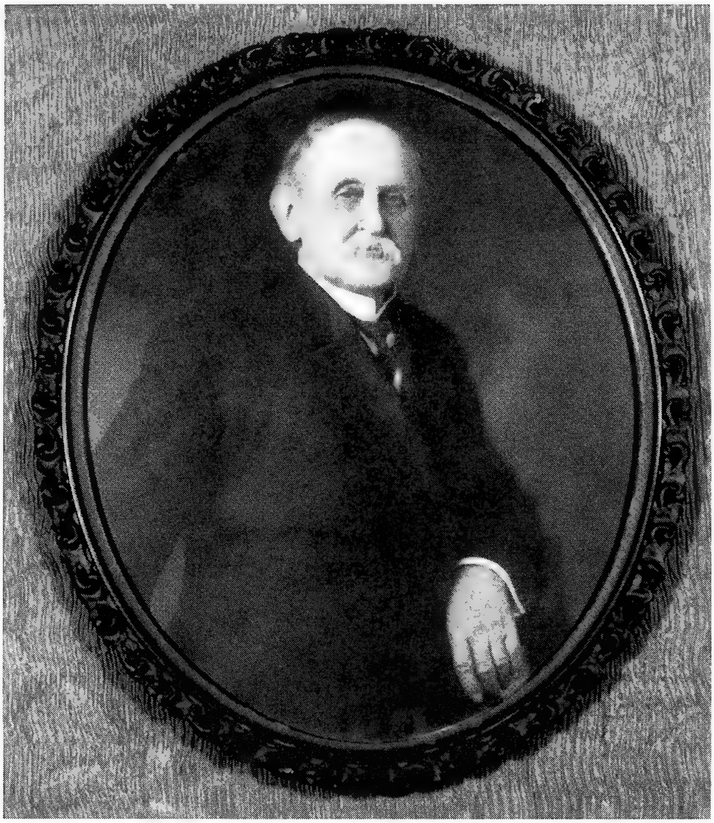
As noted, by the end of its first year, the WAS had 144 members. By mid-January of 1900, this increased to 159. At a comparable date in 1901, resident members decreased slightly to 156, but 115 non-resident members are reported. By mid-January, non-residents increased to 152 (Baker, 1902). Early in 1905, non-resident members were 167, four more than the resident members. Resident

C. Hart Merriam, first editor of the *Proceedings*. Smithsonian Institution Archives, Record Unit 95. Negative No. 23966.

members were elected by vote of the WAS membership at the annual meeting; non-residents were elected by vote of the Board of Managers. As might have been expected, some non-residents later moved to Washington and created further problems for the rules committee to sort out.

Grand Plans

After the annual meeting, on January 18, 1899, Walcott recorded: ''At survey office during the day. Meeting of Washn. Acad. Sci. 8–10 PM Elected president. Presidents reception $10^{\underline{15}}$–11 PM.''[23] At the same meeting Frank Baker, director of the National Zoological Park, was elected Secretary and he served for years in this thankless task. Bernard R. Green continued on as Treasurer until 1909, when Arthur L. Day, of the Geophysical Laboratory, at the Carnegie Institution of Washington, succeeded him. The voting for Walcott became an annual affair



Frank Baker, second Secretary of WAS. Photo, Georgetown University, Washington, DC.

which was noted as ''elected'' or ''reelected'' in his diary; the event became so sop routine that three times he neglected to write it down.

Several events occurred that year as recorded in the printed minutes. As regards the first, two special meetings were held. At the second of these, on March 15, 1899, Walcott ''Spoke on the United States National Museum before Washington Academy of Sciences $8^{\underline{15}}$–9 PM. Reception or social meeting followed''.[24] He had completed his stint as Acting Assistant Secretary of the Smithsonian Institution, but had begun the process of obtaining a new building from Congress; this was part of his successful campaign as the presence of the domed Natural History Building testifies.

Second to be recorded were seven annual addresses of presidents of affiliated societies that were given under the auspices of the WAS. Third, seven public lectures were also held under their auspices. Fourth, two receptions were held, one for the annual meeting of the NAS in the spring, and one in December when the Geological Society of America returned to Washington. Having an

Arthur L. Day, second Treasurer of the WAS. From Geophysical Laboratory, Carnegie Institution of Washington.

organization prepared to host such social events as a matter of course was surely an excellent, if unwritten, reason for forming the WAS.

Fifth, three business meetings were held. The first two established the category of non-resident member, and the third elected more resident members. Members of the WAS had the tangible benefit of receiving the *Proceedings.* Far more important, but again unwritten, as members they received the intangible benefit of prestige. University presidents, some of whom were administrators not scientists, joined the non-resident category. Those scientists who were able investigators but were not in the NAS joined. Various categories of science were set up and colleagues in Washington were encouraged to submit the names of those who might be elected as non-resident members. Through this process 208 persons were elected, though not all were seduced into paying dues. In subsequent years, recruitment of non-resident members continued, but not at such a pace.

Walcott was not a stranger to the NAS, and had spoken before the group three times prior to his election in 1896. In 1898, he added to his manifold duties that of NAS Treasurer, and served in the office until 1902. He knew that the NAS, while not ineffectual, was seldom consulted by the Congress. For the first fifty years of its existence, historians remark on only two noteworthy actions by the NAS—the reports leading to the legislation establishing the USGS in 1879, and the report leading to the setting aside of the Forest Reserves in 1897.

Walcott wanted a much stronger voice for science in Washington, better to influence Congress. He was building a power base for science, though it was not without its toll in the time required. In 1899, the Board of Managers held twenty-five meetings, the same number the next year, and eighteen during 1900. His efforts did pay dividends.

One of Walcott's immediate aims was to further higher education. Some government facilities had been opened to graduate students by Congress in 1892, but much more could be done in this regard. Walcott had the WAS pass resolutions and he ''Talked to a lot of men at A. Graham Bell's residence on movement to utilize scientific bureaus in Washn. to aid in Education''.[25] By an act of March 3, 1901, ''facilities for study and research in the Government departments, the Library of Congress, . . . shall be afforded to scientific investigators and to duly qualified individual students and graduates. . . .'' (Walcott, 1901:1004). The WAS and particularly Walcott were the driving forces in having this act pass. A provision for ''similar institutions hereafter established. . . .'' is the legal basis for students at Los Alamos, Livermore, and a host of other federal facilities. If the WAS had accomplished nothing else during its century of existence, the legacy of this legislation more than justified the formation of the organization.

In 1901, the WAS invited the American Society of Naturalists and their affiliated societies to meet in Washington and extended a similar invitation to the

AAAS. The meeting in December, 1902, was as much of a success as had been the 1891 gathering which the Joint Commission had sponsored.

Early in 1901, secretary Frank Baker wrote to a disgruntled medical doctor whose complaint was that the meetings of the WAS conflicted with those of the Medical Society. After refuting the charge, he went on to explain:

''Perhaps you may not fully realize that the object of the Academy is *not* primarily to bring out *lectures* or to give entertainments. It is for the general advancement of science at the national capital, the lectures and entertainments being merely incidental. We have at present 115 *non-resident* members who cannot, of course, attend lectures and entertainments at all.

''During the past year the Academy has progress greatly in several way. It has secured sufficient money to purchase a site for a building intended to accommodate all the affiliated societies, it has published a volume of Proceedings comprising 710 pages which will compare favorably with the publications of any similar society in the world''.[26] The accomplishments of the WAS were golden.

The Attempt for a Building

The lackluster interest of Congress in both the AAAS and the NAS graphically demonstrated that without a headquarters, an organization lacked a Washington presence and could accomplish little to influence legislation. Walcott spent part of 1899 trying to find space for the NAS in the new Library of Congress building, and elsewhere within the government structure, but without success. It was now time for the WAS to act and by 1900, the same year that Walcott was President of the Geological Society of America, he had the wheels in motion; ''Meeting on Committee on building Washn. Acad. Sci.''[27]

It was about the time that Walcott was prowling Washington to look for a NAS headquarters that he joined forces with the newly founded George Washington Memorial Association (GWMA). This was originally exclusively a national ladies organization whose aims were to honor George Washington's desire for a national university and to increase patriotic sentiment. A series of state chapters were set up to raise funds for this proposed university.

Walcott played both sides of the net in steering toward his particular goal. The GWMA emended its charter to his specifications, and within a relatively short time, each organization had appointed a committee to meet jointly. Walcott was ''At Geol. Survey for most of the day except for meeting of Committee Washn. Acad. Sci. & G.W.M.A. at Mrs. George Hearst's''.[28] Recall that patron Phoebe Hearst and Mrs. George Hearst are the same person. Two days later another meeting involved representatives of the American Association of Agricultural Colleges, and another joint meeting was held two weeks later.

Walcott continued to move both groups toward his objective of a headquarters building. By letter dated May 11, 1901, Walcott appointed himself chairman of a five person committee authorized: "1st to enter into such agreements with the George Washington Memorial Association for cooperation in the erection, maintenance, and conduct of a memorial building as may be judge necessary; 2nd to co-operate with the Executive Committee of the George Washington Memorial Association in selecting and designating incorporators".[29]

It had taken time to get all forces aligned, but it was characteristic of Walcott that once the items were in place he moved swiftly. Within a week "The incorporators of the W. [ashington] M. [emorial] I. [ntitute] met in my office 10 AM."[30] Despite inertia and disparate objects of two such dissimilar groups, by May 20 when the WMI incorporation papers were filed, they had been welded into an administrative structure which could undertake a major building project (Walcott, 1901: 1008–1010); naturally, the WMI president was Walcott.

When things began to move, Walcott kept them moving. The National Council of Education appointed a "distinguished committee of fifteen" to consider the need for a national university. They prepared a long report with included "*Resolved,* That we approve the plan for a non-Govermental Institution, known as the *Washington Memorial Institution,* to be established and maintained at Washington, D.C. for the purposes of promoting the study of science and liberal arts at the National Capitol and of exercising systematic oversight of . . . students in the Governmental laboratories and collections, . . ."[31]

The overall scheme was that the GWMA would raise money for a building and the WAS would manage it. The hope was that the National Educational Association and the Association of Agricultural Colleges and Experiment Stations would also cooperate in the venture (Baker, 1902:15). As indicated in the unpublished source noted above, by 1902, the presidents of these groups were on the advisory board of the WMI, along with cabinet members and other distinguished officials in Washington. Meanwhile, the WAS had acquired a building lot, though it may not have been in an ideal location within the city.

The founding of the WMI and its aims and aspirations received three pages in *Science* (Anonymous, 1901), plus a letter to the Editor (McGee, 1901). To keep all parties happy, in December Walcott attended the "Annual meeting of G.W.M.A. Talked to the ladies 11 30".[32]

As a result of the founding of WAS, some members of the NAS became concerned as to its motivations and sphere of influence; this upstart might do more than provide a reception at the annual meeting and it could undercut the NAS. The scientific writings and speeches of Walcott are clear. To sooth the NAS members he prepared a three-page form letter which is a classic in the field of obfuscation.

''The Washington Academy may consider such questions affecting the relations of science to the government as are not taken up by the National Academy, and which affect the entire scientific body in its relations to the Government. It may also consider the interrelationship of the various scientific organizations that unite to form the scientific body, and give such assistance that may be in its power to the correlation of scientific work and the advancement of scientific interests in the country. It was reasons such as these that led me to favor the development of the Washington Academy of Sciences. . . . I have given a great deal of time and attention to this organization the last year with the belief that it was well spent. As the same time I should take pleasure in aiding in any way in my power in the advancement of the interests of the National Academy''.[33]

That did an excellent job of muddying the waters, but the issue continued to simmer. Walcott wrote John Shaw Billings whom he had succeeded as Treasurer of NAS: ''The question of the relations of the National Academy and the Washington Academy can be talked over at the time of the meeting next month. I do not, however, see any reason for giving the subject serious consideration from the point of view that the Washington Academy is contemplating any injury to the National Academy. I think it would be best not to agitate the subject, as the impression might be given that the National Academy was endeavoring to retard and injure the Washington Academy''.[34] It is difficult to distinguish between the views of NAS Treasurer Walcott and WAS President Walcott.

The WAS was not about to supplant the NAS, but by pointing it in the direction of a headquarters building, Walcott had shocked the members of the NAS into movement of their own to that end. The hopes for a building led to more intertwining of the organizations. For example, a donation to the NAS of $300 was acknowledged by Treasurer Walcott as ''subscribed towards a building fund for a building of the Washington Academy of Sciences, National Academy of Sciences, etc.''.[35]

In 1900, Alexander Agassiz had intimated that he would provide $100,000 toward a NAS building. The following year NAS Treasurer Walcott wrote Agassiz to clarify matters between the NAS and WAS. After discussing Agassiz' presumed donation, he indicated: ''My view is that the Washington Academy and the scientific societies here should raise at least $100,000 and that the building should cost no less than $200,000 exclusive of the ground''.[36]

These are the dollars of nearly a century ago and a multiplication of 15 or 20 is needed to bring them to 1998 sums; no one ever accused Walcott of thinking small. If he had any hobby, apart from fishing, it was real estate and he was at the time involved with his third apartment building in Washington.

Another letter to Agassiz adds more details to the machinations. ''During the

past winter the Washington Academy of Sciences made an agreement with the George Washington Memorial Association after the latter had changed its charter eliminating ''national university'' to the effect that the Memorial Association was to provide the means for the erection of a building which would be the headquarters for the scientific organizations of Washington, the National Academy of Sciences and the proposed organization for post-graduate work and research in cooperation with the Government Departments.

''Mr. Alexander Graham Bell and myself are members of the Advisory Committee, and Mrs. Walcott is First Vice-President of the G.W.M.A. so we are in full touch with all that transpires within the Association''.[37] Walcott went on to add that the GWMA had $17,000 in cash and pledges for far more.

In trying to obtain support and funds for a headquarters building to give the scientific and educational organizations a physical place in Washington and a higher profile, Walcott had the highest of motives. It was more realistic than trying to found a national university. Nevertheless, put in bald terms, he had suborned the original purpose of the GWMA from campaigning for such a university to erecting a building mainly for science. To be fair, Walcott never abandoned the GWMA and as late as 1922 was chairman of their finance committee.

He continued his efforts toward greater support for education, but the 1901 law was the high water mark of that activity. To add one more tangle to the skein, as a result of the WMI Walcott became a Trustee of Columbian University. What was originally Columbia College metamorphosed into George Washington University, hardly a national establishment, but at least a token acknowledgement in the nation's capital of the original purpose of the GWMA.

Grandiose Schemes

Early in January, 1901, Secretary Baker wrote a non-resident member trying to convince him to remain with WAS. ''What we wish to do is build up an association of scientific men which will be in America what the Royal Society is to Great Britain, and thus to dignify and consolidate all branches of American science. We are therefore very careful whom we invite to membership, as you will see by scanning the list which I inclose [sic] herewith''.[38]

These were bold sentiments, indeed. Four months later, he wrote another letter to W J (''no stop'') McGee as chairman of a five man committee. ''The president of the Academy has appointed the following committee to consider: a. Whether the Washington Academy of Sciences is now a national organization. b. If not, should it become such. c. What steps are necessary to accomplish that end''.[39] Bolder sentiments.

The term grandiose used in the title of this section may be inappropriate, but grand schemes succeed, whereas grandiose ones do not; the merit of the proposal itself may ultimately not be germane to success or failure. What is evident that from about 1903 onward for the next five or six years nothing much new developed within the WAS.

Early in 1902, the WAS held a meeting at the Cosmos Club to discuss a proposed building; they had a lot and the nucleus of a building fund, but that was all the WAS had.

Another potential initiative began in February, 1903, when Walcott appointed himself chairman of a committee of four ''On the relations of the Academy to other organizations''.[40] Presumably closer association with educational groups was intended, but there is no record to support this assumption.

Matters began to slow down in a number of respects. For example, from 1904 onward the Board of Managers met eight or nine times a year; they had gathered three times as often when the WAS was growing vigorously. The WAS continued to host a social event for the NAS, and in 1907 entertained visitors coming south from the International Zoological Congress in Boston, but the concept of supporting national meetings in Washington receded. In 1906, the Board recommended that a natural scientist be appointed to the District of Columbia school board, an important enough action, but a far cry from national concern about education.

The WAS never became a national organization, nor even one of national prominence. What with resident and non-resident members being elected and resigning, and changes of address, there was a considerable load for the Secretary, but it was paper activity, not growth. A committee recommended that any member of a local society be automatically eligible to join the WAS, but nothing came of that suggestion. It may have garnered a few more supporters, but it would have cheapened the prestige of being elected to membership in the WAS.

April 24, 1909, Mrs. S. W. Dimock, long-time president of the George Washington Memorial Association who had succeeded Mrs. Hearst, addressed the WAS on the aims of the GWMA and the need for a building. It was metaphorically a cry in the wilderness. The association eventually got to a cornerstone-laying ceremony, but the building never began, for even with the merits of the cause, funds could not be raised.

The *Proceedings* became a major concern as their contents had become increasingly specialized. Add to that from Volume VIII onward, members—whether interested in the contents or not—received only about half the number of pages they had been sent in earlier years. Walcott left office just after volume XII was completed.

In 1905, there was discussion of a weekly newsletter, but it never matured, as

there simply was not that much local society news. However, these discussions may have laid the seeds for a monthly *Journal,* and that new series began in 1911. The Board of Managers agreed that the *Proceedings* would be phased out with only two issues that final year.

The Board was surprised when a third brochure came out in August and several of the Managers were quite upset that there was no announcement that the series was to end. The WAS treasury was no longer fat, and money was grudging appropriated to pay the bills for this printing. The reaction to this third brochure was mild compared to that when another issue appeared in November; at least that one finally announced the end of the *Proceedings.* There simply was no money not already committed to the *Journal* and the Board was asked to make individual contributions to bail out the editor. It was not a happy time for the Treasurer, the Managers, or the former editor who was not listed as a member of the new editorial board for the *Journal.*

Discussion

Considering what had been accomplished in slightly more than a decade, the early history of the WAS certainly cannot be deemed a failure. However, the change between the first few years of Walcott's tenure and his later years as president of WAS deserve comment. In a nutshell, Walcott was foundering from an overload of administrative duties. Unfortunately by reelecting him year after year the membership of the WAS refused to recognize that fact.

In a reprise of his 1897 activities, in December of 1901, Walcott met Andrew Carnegie. The Carnegie Institution of Washington (CIW) was teetering on the edge of never being born, but Walcott rescued it, incorporated it in January of the following year and became its secretary for three years (Yochelson, 1994); the secretaryship turned out to be a far more complex job than anyone, least of all Walcott, had anticipated. Of course, he was still the director of the ever-growing USGS. Almost immediately after incorporating the CIW, the reclamation of western lands came to the fore. At the insistence of President Roosevelt, the 1902 Reclamation Service became part of the USGS because Roosevelt wanted it run right.

Although there are parallels, these duties presented a more complex and demanding role than that Walcott faced five years earlier, when he was running the National Museum and had the Forest Reserves piled on the USGS. To add to that, in 1903, President Roosevelt had him chair, not one, but two committees. He was always a prolific scientist, but in 1903, only one two-page paper and remarks at the Powell Memorial meeting (Walcott, 1903) are on his bibliography. In 1904, only the annual report of the USGS is recorded.

Walcott was swamped, yet he did manage to keep the WAS going, even if it was essentially marching in place. He simply could not keep the Carnegie Institution of Washington moving forward and simultaneously pursue the interests of the WMI and the GWMA. Many onlookers could not figure out what the relationship of the CIW was to the other organizations. Funding which might have come to the WAS or WMI dried up in the face of the massive Carnegie endowment and uncertainty as to what it might support.

To partially balance the scales, in May 1901, Walcott had convinced Daniel Coit Gilman, retiring president of the Johns Hopkins University to serve as chairman of the WMI. That fall Walcott wrote to Rockefeller and to Carnegie asking for money to support the WMI. Unknown to Walcott, Gilman was advising Andrew Carnegie and it was he who brought the two men together.

In the long run, keeping the CIW on track did much more for science than a headquarters building in Washington would have accomplished; it would be many years before ''public interest'' lobbying became significant. Although the WAS played an indirect role through the founding of the WMI and the resulting contact with Andrew Carnegie, the organization can take pride in at least tangentially helping to found the CIW.

With all his load, still before leaving the USGS in 1907 and starting another major chapter in his research, Walcott did lay the foundation for the Bureau of Mines. What the WAS might have accomplished had president Walcott been less burdened is another piece in the great history game of ''what if.''

Of course, one can turn ''what if'' on its head. After shedding his responsibly as president of the WAS, Walcott again became active. In 1911, he helped found the Research Corporation with F. C. Cottrell (Cameron, 1952) and in 1916 the National Research Council with George Ellery Hale. He founded the National Advisory for Aeronautics in 1915, and he was President of the National Academy of Sciences from 1916 until 1922. All this was done while he became the second-most effective Secretary in the history of the Smithsonian Institution, and still carried on a major field research program in western Canada. Who can say what this paragon might have accomplished had he not been saddled with the WAS and had turned the helm over to others in 1903. However one wants to play the ''what if'' game, Walcott continued as a member of the WAS until his death on February 9, 1927.

Conclusion

Thursday, January 19th 1911, the 13th annual meeting of the WAS was held in the Cosmos Club; at this point 13 societies were affiliated. Walcott jotted in

Barton W. Evermann, third editor of the *Proceedings*. From Division of Herpetology, California Academy of Sciences.

his diary: ''Meeting of the Washington Academy $4^{\underline{40}}$ p.m. This closes my eleventh (11th) year as President of the Academy''.[41] Frank Wigglesworth Clarke, Chief Chemist of the USGS, not Walcott, was elected president.

''Especially felicitous remarks were made by Mr. Walcott, the retiring president, and Prof. Clarke, the newly elected president. On motion of Dr. Kober, the Academy extended to Mr. Walcott a hearty vote of thanks for his long and successful services as president of the Academy. On motion of Mr. Walcott, a

similar vote of thanks was extended to all the officers who had contributed to the successful work of the Academy. At 6:20 the Academy adjourned''.[42]

It was the end of an era in several respects. Thereafter, presidents of WAS changed each year. This also marked the stop of the *Proceedings* and the start of the *Journal of the Washington Academy of Sciences.* Increasing administrative efforts at the Smithsonian and a strenuous research program with months in the field each year, limited Walcott's participation in the affiliated societies. According to the WAS directory, in 1911, he still retained membership in the Biological, Geological, National Geographic, and American Foresters societies. From 1903 onward, Mrs. Walcott was listed as a member of the Archaeological Society; she was killed in a train accident in 1911. In 1913, Walcott was listed only as in the Archaeological and Geological societies; presumably he carried on her membership.

By 1919, the directory no longer listed affiliations to other local societies. In a sense this was an indication of the increasing specialization of science and the increasingly harried pace of life, both consequences of that great watershed in Washington, the first World War.

After Walcott's death, at the 288th meeting of the Board of Managers, February 23, 1927, a committee of three was appointed to draft an appropriate resolution. C. G. Abbot, Acting Secretary of the Smithsonian Institution, L. O. Howard, the leading entomologist in the Department of Agriculture, and F. C. Cottrell, chemist and long-time friend, wrote: ''the Washington Academy of Sciences hereby records its profound sense of loss occasioned by the death of its member and former president, Charles Doolittle Walcott, and its sympathy for his family''.[43]

Acknowledgements

Without the Centennial celebration of the Washington Academy of Sciences, there would be no reason for this paper. Dr. John Proctor kindly arranged for me to participate in this event and made pertinent comments on several drafts. Miss Diana M. Hawkes, Haselmere Educational Museum, Haselmere, England, took time from her busy schedule to search for Archibald Geike letters and then to transcribe five of them for my edification. The Smithsonian Institution Archives continues its tradition as a fine place to conduct research; among other help he provided, Mr. James Steed arranged for nearly half of the illustrations used herein. Mr. J. McGregor of the U.S. Geological Survey Photographic Library, Denver, was his usual helpful self in securing another photograph. Dr. A. Leviton, California Academy of Sciences, allowed copying of a picture of B. W. Evermann; Dr. H. S. Yoder, Jr., of the Carnegie Institution of Washington, provided the photo-

graph of A. L. Day. The archives of Georgetown University seemingly are the only repository in Washington of a picture of Frank Baker, and efforts to copy it are greatly appreciated.

Notes

In a strict sense, the directories of the Joint Commission and the Washington Academy of Sciences are publications, not unpublished sources, but they are ephemeral. The archives of the WAS are in the Smithsonian Institution Archives under Record Unit 7099. Box 43 contains all ten of the Joint Commission directories, and perhaps the most complete set of the WAS directories extant. Unless otherwise indicated all notes are to unpublished documents in RU 7099.

1 The ''Directory of the Scientific Societies of Washington comprising the Anthropological, Biological, Chemical, National Geographic and Philosophical Societies'' is anonymous for purposes of cataloging, although the secretary of the Joint Commission is included as one of the officers listed. One copy of the third directory is inscribed ''With the compliments of James C. Pilling.'' Pilling was the Chief Clerk of the U.S. Geological Survey and also the Bureau of Ethnology and was—literally—Powell's right hand man, and is a likely candidate for the person who actually did the work of compiling lists and preparing copy for the printer. Marcus Baker, the first secretary of the Joint Commission, was also an employee of the USGS.

The first directory was issued in February, 1889 (39 pages) and annually thereafter: February, 1890, (43 p.); March 18, 1891 (57 p.); March 10, 1892 (58 p.) [This edition carries Entomological in the title; the Entomological Society of Washington was founded February 28, 1884.]; February 10, 1893, 71 p. [This edition adds Geological to the title; the Geological Society of Washington was organized February 25, 1893]; February 10, 1894, 67 p. [Membership continued to grow and the lesser number of pages reflects a smaller type face in the directory]. February 25, 1895, 44 p. [Information on place of employment was dropped and a smaller type size used]; February 21, 1896, 53 p.; February 15, 1897, 51 p.; and February 17, 1898. This was the 10th and final year of publication by the Joint Commission and was a supplement to the 1897 directory of 23 pages. It consisted of 19 pages of additions and corrections of addresses, and one page of those who apparently no longer had membership in any of the societies. Record Unit 7009, Box 1. [The cooperative nature of this directory is indicated in the minutes of the Geological Society of Washington. The first year the GSW was listed it was accessed \$20.70 for $8\frac{99}{100}\%$ of the cost; in 1897 the GSW was accessed \$60.75 for 8.33% of the costs and the council demanded an itemized statement].

2 ''Directory . . .'' 1895, p. 9. Box 1.

3 ''Directory . . .'' 1896, p. 10–13. Box 1.

4 Geike to Hubbard, 28 June, 1896. Geike letter book, December 1895–October, 1896, pp. 319–320. Haselmere Educational Museum, Haselmere, England.

5 The events are discussed in the ''Geological Society of Washington minutes of the meetings of the council 1893–1900'' catalogued as G (226) q W 24.98, in the rare book room of the USGS library, Reston, Virginia. The first step of the drama is on p. 99.

6 Geike to Emmons, 8 January, 1897. Geike letter book, October 1896–June, 1897, pp. 188–189. Haselmere Educational Museum, Haselmere, England.

7 Geike to Hubbard, 18 March, 1897, pp. 375–376.

8 Geike to Emmons, 18 March, 1897, pp. 377–378.

9 Geike to Hague, 18 March, 1897, pp. 402–403.

10 Minutes of the Proceedings of the Joint Commission of scientific societies of Washington from 1897 to —. April 6, 1897, p. 15–16. Box 1.

11 Geological Society . . . , May 26, 1897, p. 126.

12 Minutes of the Proceedings . . . , January 11, 1898, p. 21. Box 1.

13 Minutes of the Proceedings . . . , January 25, 1898, p. 41. Box 1.

14 Walcott's daily diaries are in chronological order within RU 7004. This quote is from February 4, 1898, Box 13.

15 Outgoing correspondence of the Secretary, January 10, 1907, p. 161. Box 8.

16 ''Directory . . .'' 1903, p. 3. One slight difference between the WAS directory and its JC predecessor was the brilliant red paper covers.

17 The forms which were returned by members are in alphabetical order in Box 43, along with the directories of the JC and WAS.

18 ''Directory of the Washington Academy of Sciences and Affiliated Societies comprising the Anthropological, Biological, Chemical, Entomological, Geographic, Geological Historical, Medical, Philosophical'' {Historical (The Columbia Historical Society, founded May 3, 1894, met at the Shoreham Hotel], and Medical [The Medical Society of the District of Columbia was first chartered February 16, 1819, and

revived July 7, 1838; it met weekly] were added to the original title}, February 24, 1899, 67 p.; February 19, 1900, 63 p.; Thirteenth year of publication, March, 1901, 67 p.; Fourteenth year of publication, March 28, 1903, 68 p. {Archeological [The Archaeological Institute of America was founded in Boston in 1879; the Washington Society or Chapter was founded April 7, 1902, and met irregularly] and Botanical [formed November 28, 1901 out of fusion of two informal groups were added to the title. [For the Archeological and National Geographic only local members were listed; the total of memberships for the year was 2,158. There were still a large number of multiple memberships; Walcott is listed in the Anthropological, Biological, Geographic, Geologic, Philos[phical. Mrs. Walcott is listed as a member of the Archeological]; Fifteenth year of publication, February 28, 1905, 72 p. {Foresters [The Society of American Foresters was organized November 30, 1900, and originally met at the home of Gifford Pinchot] [Archeological changed to Archaeological] was added to title}. [This is the first edition that did not include a summary of the society memberships]. Sixteenth year of publication, February 28, 1907, 87 p. {Engineers [The Washington Society of Engineers was organized November 23, 1905, and met at National Geographic Society Hubbard Hall] was added to title; Seventeenth year of Publication, March 11, 1909, 67 p. [In the 1909 edition Walcott was listed as also being in the Society of American Foresters].

In addition to the above directories, Box 43 contains biannual directories for 1911–1927 [1921 is missing], 1930, 1932, 1935, 1937, 1939, and 1941, all as part of a continuously numbered series. The 1941 edition is printed from a typescript and is the first not to include a calendar of meetings. A few directories were published in the post-World War II years, but mainly the WAS published only a list of its members.

[19] Some mechanical details of the *Proceedings* are summarized below. For volumes I and II, C. Hart Merriam, Biological Survey, is listed as Editor; III–V, Marcus Baker, then Assistant Secretary, Carnegie Institution of Washington; VI–XIII, Barton W. Evermann, Bureau of Fisheries.

I. 1899 (April, 1899–February, 1900). Pages xii + 347 numbered pages, including 6 p. index. Eight articles, 26 pls., 11 figs. [Includes as one article "First Annual Report of Secretary and of Treasurer," 1–14]. [Rules for publication are given on xi-xii, and irregularly repeated in other volumes].

II. 1900 (March–December). xiv + 694 p., including 17 p. index. 36 articles, 37 pls., 43 figs.

III. 1901 (March–December). ix + 612 p., including 6 p. index. 22 articles, plus one brief obituary, 65 pls., 66 figs.

IV. 1902 (March–October). vi + 573, including 12 p. index. 13 articles, 35, pls. 22 figs. [Includes as one article "Organization and Membership of the Washington Academy of Sciences, 1902" which contains second–fourth annual reports of Secretary and Treasurer].

V. 1903. (January, 1903–February, 1904). vii + 429 p., including 6 p. index. Five articles, plus notices of deceased members, 22 pls.

VI. 1904. (October, 1904–February, 1905). viii + 481 p., including 9 p. index. Five articles, 34 pls. 81 figs. [Includes as one article "Organization and Membership of Washington Academy of Sciences, 1904," which contains fifth-seventh annual reports, 439–472].

VII. 1905 (June, 1905–March, 1906). xii + 402 p., including 5 p. index. 12 articles, 14 pls., 7 figs. [Includes eighth annual reports, ix–xii].

VIII. 1906 (May, 1906–March, 1907). xiii + 491 p., including 4 p. index. 12 articles, 27 pls. [Includes ninth annual reports, ix–xii].

IX. 1907 (July, 1907–February, 1908). vi + 558 p., including 9 p. index. Nine articles, 15 pls., [Includes as one article "Organization and Membership of Washington Academy of Sciences, 1906, which includes tenth annual reports, p. 523–547.].

X. 1908 (July–December). x + 248 p., including 3 p. index. Three articles, plus short obituaries, p. 189–243, 2 pls. 3 figs.

XI. 1909. (March–December). ix + 299 p., including 4 p. index. Six articles, no illustrations.

XII. 1910. (January–December). xi + 330 p., including 2 p. index. Three articles, 1 pl., 3 figs.

XIII. 1911. (February–November). vi + 101 p., including 3 p. index. Four articles, plus price list of 13 p., 5 pls.

As indicated in the price list, volumes I, X, XI, XII (and presumably XIII) cost $3.00 paper bound and $4.00 cloth bound; II–IX were priced at $4.50 and $5.00 respectively. One handwritten slip in Box 11, folder 2, summarizes the printing costs of most volumes: I - $1,162.19; II - $2,351.99; III - $1,655.72; IV - $1,707.82; V - $1,729.53; VI - $1,430.46; VII - $1,333.01; VIII - $1,000.70. The original press run was 1,000 copies; in volumes IV and VI it is given as 1,200. Some of the variation in price may be related to the number of illustrations. The stock of *Proceedings* was stored in Evermann's basement. There is an inference that many copies were on hand; where they eventually went is another minor mystery.

[20] Outgoing correspondence of Secretary, January 4, 1901, p. 35. Box 8.

[21] Outgoing . . . , January 12, 1901, p. 45, 46. Box 8.

[22] Walcott diary . . . , December 13, 1901. RU 7004, Box 14.

[23] Walcott diary . . . , January 18, 1899, RU 7004, Box 13.

[24] Walcott diary . . . , March 14, 1899. RU 7004, Box 13.

[25] Walcott diary . . . , January 17, 1901, RU 7004, Box 14.

[26] Outgoing . . . , January 12, 1901, Box 8.
[27] Walcott diary . . . , May 18, 1900. RU 7004, Box 13.
[28] Walcott diary . . . , March 11, 1901. RU 7004, Box 14.
[29] Outgoing . . . , May 11, 1901, Box 8.
[30] Walcott diary . . . , May 16, 1901, RU 7004, Box 14.
[31] The resolution is quoted from pages 8–9 of an anonymous pamphlet ''History of the organization of the George Washington Memorial Association and the Washington Memorial Institution''; a date of 1902 is written on it. This document occurs in the GWMA file of the Walcott papers, RU 7004, Box 43, Folder 14. Presumably this pamphlet was prepared for purposes of fund raising.
[32] Walcott diary . . . , December 14, 1901. RU 7004, Box 14.
[33] Three-page form letter reproduced by mimeograph or similar method. It is unknown how many were distributed and to whom, but is has been found in the files of several NAS members; it may also have been sent to prospective members. A copy is pasted in a WAS scrapbook, Box 30.
[34] Letterbook of Treasurer, C. D. Walcott and S. F. Emmons, to John Shaw Billings, March 22, 1901. National Academy of Sciences Archives.
[35] Letterbook . . . , to W. Sturgis Bigelow, April 22, 1901, p. 129.
[36] Letterbook . . . , to Alexander Agassiz, March ?. 1901, p. 42.
[37] Letterbook . . . , to Alexander Agassiz, April 1, 1901, p. 124–125.
[38] Outgoing . . . , January 21, 1901, p. 41. Box 8.
[39] Outgoing . . . , May 11, 1901, Box 8.
[40] Outgoing . . . , February 12, 1903, Box 8.
[41] Walcott diary . . . , January 19, 1911, RU 7004, Box 15.
[42] Minutes of the Recording Secretary, January 19, 1911. Box 1.
[43] Minutes of the Board of Managers, January 31, 1910–December 19, 1929. Box 2.

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WASHINGTON ACADEMY OF SCIENCES Bylaws (Approved by the Board of Managers March 12, 1997 and the Membership of the Academy by vote in 1997)

ARTICLE 1. OBJECTIVES

Section 1. The objectives of the Washington Academy of Sciences (hereinafter called the Academy) shall be: (a) to stimulate interest in the sciences, both pure and applied; and (b) to promote their advancement and the development of their philosophical aspects by the Academy membership and through cooperative action by the Affiliated Societies.

Section 2. These objectives may be attained by, but are not limited to: (a) publishing a periodical, occasional scientific monographs and such other books or pamphlets as may be deemed desirable; (b) conducting public lectures of broad scope and interest in the fields of science; (c) sponsoring a Washington Junior Academy of Sciences (WJAS); (d) promoting science education and a professional interest in science among people of high school and college age; (e) accepting or making grants of funds to aid special research projects; (f) convening symposia, both formal and informal, on any aspects of science; (g) calling scientific conferences; (h) organizing or assisting in scientific assemblies or bodies; (i) cooperating with other academies and scientific organizations; (j) awarding prizes and citations for special merit in science; (k) maintaining an office and staff to aid in carrying out the objectives of the Academy.

Section 3. (Moved from previous Article XIII). The Washington Academy of Sciences is organized exclusively for charitable, educational and scientific purposes, including, for such purposes, the making of distributions to organizations

that qualify as exempt organizations under Section 501(c)(3) of the U.S. Internal Revenue Code (or the corresponding provision of any future United States Internal Revenue Law).

ARTICLE II. MEMBERSHIP

Section 1. The Academy shall be comprised of individuals, Affiliated Societies and Sustaining Associates. Throughout this document when reference is made to individuals, the use of ''he'' shall be interpreted as ''he or she.''

Section 2. *Members* shall be individuals who are interested in and will support the objectives of the Academy and who are otherwise acceptable to at least two-thirds of the Committee on Membership. A letter or application form requesting membership and signed by the applicant may suffice for action by Committee; approval by the Committee constitutes election to membership.

Section 3. *Fellows* shall be individuals who by reason of original research or other outstanding service to the sciences, mathematics, or engineering are deemed worthy of the honor of election to academy fellowship.

Section 3(a). Nominations of Fellows shall be presented to the Committee on Membership on a form approved by the Committee. The form shall be signed by the sponsor (a Fellow who has knowledge of the nominee's field), and shall be endorsed by at least one other Fellow. An explanatory letter from the sponsor and supporting material shall accompany the completed nomination form.

Section 3(b). Election to fellowship shall be by vote of the Board of Managers upon recommendation of the Committee on Membership. Final action on nominations shall be deferred at least one week after presentation to the Board of Managers, where two-thirds of the vote cast shall be necessary to elect.

Section 3(c). Each individual (not already a Fellow) who has been chosen to be the recipient of an Academy Award for Scientific Achievement shall be considered nominated for immediate election of fellowship and will not be required to pay annual dues for the current year.

Section 3(d). Any fellow of the Academy may recommend in writing that an individual of national eminence be considered for immediate election to fellowship by the Board of Managers, without the necessity of compliance with the procedures of Sections 3(a) and 3(b) of this Article.

Section 4. Patrons. Members or Fellows who have given to the Academy not

less than one thousand dollars, or its equivalent in property or tangible assets, shall be eligible for election by the Board of Managers as Patrons of the Academy (for life).

Section 5. *Life Members* or *Life Fellows* shall be those individuals who have made a single payment in accordance with Article II. Section 11(a) in lieu of annual dues.

Section 6. Members or Fellows in good standing who are retired and are no longer engaged in regular gainful employment may be placed in emeritus status. Individuals in emeritus status shall be designated an *Emeritus Member* or *Emeritus Fellow* as appropriate. Upon request to the Vice President for Membership Affairs for transfer to this status, they shall be relieved of further payment of dues, beginning with the following January first; shall retain rights to hold office and attend meetings, shall receive notices of meetings without charge; and at their request, shall be entitled to receive the Academy periodical at cost.

Section 7. Members or Fellows living more than 50 miles from the White House, Washington, DC shall be classed as *Nonresident Members* or *Nonresident Fellows.*

Section 8. An election to any dues-paying class of membership shall be void if the candidate does not within three months thereafter pay his dues or satisfactorily explain his failure to do so.

Section 9. Former Members or Fellows who resigned in good standing may be reinstated upon application to the Vice President for Membership Affairs for approval by the Board of Managers. No reconsideration of the applicant's qualifications need be made by the Membership Committee in these cases.

Section 10. Dues. Annual dues for each membership class shall be fixed by the Board of Managers. No dues shall be paid by Emeritus Members, Emeritus Fellow, Life Members, Life Fellows, Patrons, or Affiliated Societies.

Section 10(a). Members and Fellows in good standing may be relieved of further payment of dues by making a single payment that has a value equal to ten years of dues current at the time of payment. (see Article II, Section 5) Such persons are to be identified as Life Members for Life Fellows as appropriate. Income from this source shall be identified as the Life Membership Endowment Fund (LMEF). All decisions regarding investments in the LMEF will be made by a two-thirds vote of the Board of Managers, after Board Members have received advanced notice of such action.

Section 10(b). Individuals whose dues are in arrears for one year (counting from the ''dues payable date'' on the latest dues payment bill) shall neither be entitled to receive Academy publications nor vote in Academy elections.

Section 10(c). Individuals whose dues are in arrears for twenty-four (24) months (counting from the ''dues payable date'' on the latest dues payment bill) shall be dropped from the rolls of the Academy, upon notice to the Board of Managers, unless otherwise directed. Those who have been dropped from membership for nonpayment of dues may be reinstated upon approval of the Board of Managers and upon payment of back dues for two years together with dues for the year of reinstatement.

Section 11. *Affiliated Societies.* Bona fide scientific societies may apply for affiliation with the Academy by furnishing to the Secretary of the Academy an outline of their objectives, organizational structure and requirements for membership in their society. The Secretary will transmit the application to the Policy and Planning Committee for review and recommendation for action by the Board of Managers.

Section 11(a). Each Affiliated Society shall select one of its members, who is also a member or fellow of the Academy, to serve as its delegate to the Board of Managers. The delegate shall serve until replaced by his society.

Section 11(b). Each Affiliated Society shall cooperate with the Academy in sponsoring joint meetings of general scientific interest.

Section 12. *Sustaining Associates.* Any association, corporation, firm, institution or subdivision thereof, which has an interest in promoting the objectives of the Academy may be invited by the President of the Academy, with the approval of the Board of Managers, to become a Sustaining Associate for the purpose of supporting the Academy and its programs. The names of the Sustaining Associates shall be listed annually in the Journal of the Washington Academy of Sciences.

Section 12(a). Each Sustaining Associate shall designate a person to serve as liaison to the Washington Academy of Sciences. This individual will receive the Journal of the Washington Academy of Sciences and mailings regarding upcoming technical meetings. The position shall be non-voting unless the liaison is concurrently an individual Member or Fellow of the Academy.

ARTICLE III. ELECTED OFFICERS AND BOARD MEMBERS

Section 1. Officers of the Washington Academy of Sciences shall be President, President-Elect, Vice President for Administrative Affairs, Vice President for

Membership Affairs, Vice President for Affiliate Affairs, Vice President for WJAS Affairs, Secretary, and Treasurer. All shall be chosen from resident fellows of the Academy.

Section 2. *The President* shall appoint all committees and such nonelective officers as needed unless otherwise directed by the Board of Managers or provided in the bylaws. He (or his substitute; the President-Elect, the Vice President for Administrative Affairs, the Vice President for Membership Affairs, the Vice President for Affiliate Affairs, the Vice President for WJAS Affairs, the Secretary, or the Treasurer, in that order) shall preside at all meetings of the Academy, the Board of Managers and the Executive Committee.

Section 3. *The President-Elect* shall succeed to the office of President following one term as President-Elect. The President-Elect shall serve as Chair of the *Program Planning Committee* to arrange speakers and meeting places for the following year (the year in which the President-Elect succeeds to President).

Section 4. The *Vice President for Membership Affairs* shall have general responsibilities for committees related to membership; the Membership Committee, the Membership Promotion Committee, and the Committee on Awards for Scientific Achievement.

Section 5. *The Vice President for Administrative Affairs* shall have general responsibility for operation of the Business Office of the Academy and the Journal of the Washington Academy of Sciences. He shall oversee the activities of the Editorial Advisory Committee, the Home Page Committee, and the Office Manager. In the absence of the Archivist the Vice President for Administrative Affairs shall assure that the historical records of the Academy are maintained permanently at a secure and accessible location.

Section 6. *The Vice President for Affiliate Affairs* shall serve as Chair of the Affiliates Society Representatives. He shall maintain a current list of Affiliated Societies, their presidents and representatives to WAS. He shall maintain liaison with the delegates of the Affiliates and keep them informed of WAS meetings and events.

Section 7. *The Vice President for WJAS Affairs* shall have general responsibility for the committees relating to organizing and maintaining the Junior Academy (WJAS). He shall have responsibility for the Committee for Encouragement of Science Talent and the Committee on Grants-In-Aid for Scientific Research. He shall interface with the Joint Board on Science and Engineering Education.

Section 8. *The Secretary* shall act as secretary to the Board of Managers and to

the Academy as a whole. He shall record and distribute the minutes of the meetings of the Board of Managers and such other meetings as the Board of Managers may direct. He shall conduct all correspondence relating thereto except as otherwise provided and shall be the custodian of the Corporate Seal of the Academy. He shall be responsible for keeping the working records of the Academy current.

Section 9. The *Treasurer,* in cooperation with the Vice Presidents for the functional areas described in Sections 4, 5, 6, and 7, above, shall be responsible for preparing the Budget of the Academy and submitting it to the Board of Managers for approval. The Treasurer shall also be responsible for distributing to the Board of Managers in a timely manner records of funds received and expended. The Treasurer shall be responsible for maintaining records of funds deposited in banks or other savings instruments. The Treasurer and/or other designated persons shall sign checks for disbursements of funds as directed by the Board of Managers. The Treasurer shall prepare annual reports as required by the Internal Revenue Service, the U.S. Postal Service, etc. He also shall deposit and disburse funds of the Washington Junior Academy of Sciences.

Section 10. The President and the Treasurer, as directed by the Board of Managers, shall jointly sign securities belonging to the Academy and endorse financial and legal papers necessary for the uses of the Academy, except those relating to current expenditures authorized by the Board of Managers. In case of disability or absence of the President or Treasurer, the Board of Managers may designate the President-Elect or another elected officer as Acting President and/or another elected officer of the Academy as Acting Treasurer, who shall perform the duties of these offices during such disability or absence.

Section 11. When for approved Academy obligations, circumstances necessitate payment by persons other than the Academy officers who sign checks, reimbursement to such persons shall be made only when appropriate documentation is submitted to the Treasurer of the Academy.

Section 12. Two Members or Fellows of the Academy shall be elected each year to serve a three-year term as *Members of the Board* of Managers. To initiate staggered terms or to fill vacancies, additional Members of the Board of Managers may be selected in the annual election.

Section 13. The newly elected officers and Members of the Board of Managers shall take office at the close of the annual meeting, when the President-Elect of the previous year becomes President.

ARTICLE IV. APPOINTED OFFICERS

Section 1. An *Office Manager may* be appointed by the Board of Managers. The Office Manager shall be responsible for the routine business operation of the Academy. The Board of Managers shall determine the type of business activity (volunteer workers or contract workers) and the amount of funds to be allocated to the business office.

Section 2. An *Editor* for the Journal of the Washington Academy of Sciences shall be appointed by the Board of Managers. He shall receive advice from the Editorial Advisory Committee. The Editor shall be responsible to the Vice President for Administrative Affairs for administrative policy and related activities.

Section 3. An *Archivist* may be appointed by the President. If appointed he shall maintain the permanent records of the Academy, including important records which are no longer in current use by the Secretary, Treasurer or other officer, and such other documents and material as the Board of Managers may direct. The Archivist shall assure that historical records are maintained permanently at a secure and accessible location.

ARTICLE V. BOARD OF MANAGERS

Section 1. The activities of the Academy shall be guided by the Board of Managers, consisting of the President, President-Elect, immediate Past President, four Vice Presidents, Secretary, Treasurer, six elected members of the Board of Managers, and one delegate nominated by each of the Affiliated Societies. The Editor of the Journal of the Washington Academy of Sciences and the Office Manager shall be members *ex officio* of the Board of Managers.

Section 2. The Board of Managers shall set the dues for individual members and the minimum contribution for Life Members, Life Fellows, Patrons and Sustaining Associates. For prolonged, diligent and well-documented service in the administrative work of the Academy the Board of Managers may recognize such service of a Member or Fellow by citation including dues paid for life.

Section 3. The Board of Managers shall transact all business of the Academy not otherwise provided for in these Bylaws. A quorum of the Board shall be one fourth of the membership of the Board of Managers. To be eligible to vote, the officer or member of the Board of Managers must be in good standing, casting one vote only regardless of the number of offices or Affiliated Societies that he may represent.

Section 4. The Board of Managers may provide for such standing and special committees as it deems necessary.

Section 5. The Board of Managers shall have power to fill all vacancies in its elected membership until the next general election. This does not apply to the offices of the President and Treasurer or to delegates of Affiliated Societies.

ARTICLE VI. COMMITTEES

Section 1. An **Executive Committee** shall have cognizance of Academy finances by reviewing the Treasurer's monthly reports of budgeted expenses and anticipated income, and by reviewing the status of several internal accounts; the Life Membership Endowment Fund, the I.R.S. Form 990 accounts, the U.S. Postal Accounts, the WJAS Account, etc.

Section 2. The **Executive Committee** shall meet at the call of the President. It shall conduct all day-to-day business not requiring Board approval, and it shall prepare issues and positions in advance of Board of Managers meetings.

Section 3. The **Executive Committee** shall consist of the incumbent elected officers of the Board of Managers plus two non-elected members appointed by the President.

Section 4. Committees under the cognizance of the President are the **Executive Committee, the Nominating Committee, the Policy and Planning Committee, and the Audit Committee.**

Section 5. Committees under the cognizance of the President-Elect are the **Program Planning Committee.**

Section 6. Committees under the cognizance of the Vice President for Administrative Affairs are the **Editorial Advisory Committee**, and the Home Page Committee.

Section 7. Committees under the cognizance of the Vice President for WJAS Affairs are the **Committee on the Encouragement of Science Talent, Committee on Grants-in-Aid for Scientific Research.**

Section 8. Committees under the cognizance of the Vice President for Membership Affairs are the **Membership Committee, the Membership Promotion Committee, the Committee on Awards for Scientific Achievement.**

Section 9. The President shall appoint from the Academy membership such ad hoc committees as are authorized by the Board of Managers and such special

committees are necessary to carry out its functions. Committee appointments shall be staggered as to term whenever it is determined by the Board of Managers to be in the interest of continuity of committee operations.

Section 10. The President, with the approval of the Board of Managers, shall appoint a **Nominating Committee** of six fellows of the Academy, (see Article VI. Section 4) at least one of whom shall be a Past-President of the Academy, and at least three of whom shall have served as representatives of Affiliated Societies for at least one year. The Nominating Committee shall be appointed no later than the November meeting of the Board of Managers (or November 15).

Section 11. The President shall appoint a **Committee of Tellers**, of three Members or Fellows no later than the December meeting of the Board of Managers (or December 15).

Section 12. The **Nominating Committee** shall prepare a slate listing one or more persons for each of the offices of President-Elect, the four Vice Presidents, Secretary, Treasurer, and four or more persons for the two Members of the Board of Managers whose terms expire after three years at at least two persons for each vacant unexpired term of such position (see Article III, Section 11). The slate shall be presented for approval at the meeting in December. Not later than December 15, the Vice President for Administrative Affairs shall forward to each Academy member and fellow an announcement of the election, the Committee's nominations for the offices to be filled, including biographies of nominees, and a list of incumbents. Additional candidates for such offices may be proposed by any Member or Fellow in good standing by letter received by the Vice President for Administrative Affairs not later than January 3. The letter shall include the concurrence of each nominee and the names of at least 15 members or fellows making the proposal. Upon verification by the nominating committee the names shall be entered on the ballot. The Vice President of Administrative Affairs shall remind Members and Fellows of the foregoing option with the distribution of the preliminary slate.

Section 13. Not later than February 15, the Vice President for Administrative Affairs shall prepare and mail ballots to members and fellows. Independent nominations shall be included on the ballot, and the names of the nominees shall be arranged in alphabetical order. When more than two candidates are nominated for the same office, the voting shall be by preferential ballot in a manner prescribed by the Board of Managers. The ballot shall contain a notice to the effect that votes not received by the Vice President for Administrative Affairs before the

first Thursday of March, and votes of individuals whose dues are in arrears for one year or more, will not be counted. The Committee of Tellers shall count the votes and report the results at the April Meeting of the Board of Managers.

Section 14. The President shall, in advance of the Annual Meeting, appoint an **Auditing Committee** consisting of three persons, none of whom are a current officer, to audit the accounts of the Academy.

ARTICLE VII. MEETINGS OF THE ACADEMY

Section 1. The annual meeting of the Academy shall be held in the Washington, D.C. area each year in May. It shall be held on the third Thursday of the month unless otherwise directed by the Board of Managers. At this meeting, the reports of the President the Secretary, the Treasurer, and the Audit Committee shall be presented.

Section 2. *Regular meetings* of the Board of Managers shall be set preferably for a fixed place, hour, day of week, and sequence of months excepting July and August. Other meetings may be held at such time and place as the Board of Managers may determine.

Section 3. *Special Meetings* of the Board of Managers shall be held as called by the President, or in his absence by the President-Elect, or within ten days after a written request by six members of the Board of Managers has been received by the Secretary, he is required to convene a special meeting of the Board of Managers to address the specific issues for which the meeting was requested.

Section 4. The rules contained in ''Robert's Rules of Order Revised'' shall govern the Academy in all cases to which they are applicable, and in which they are not inconsistent with these Bylaws or special rules of order of the Academy.

ARTICLE VIII. REMOVAL FROM OFFICE

Section 1. Members of the Board of Managers and the Executive Committee shall assure that all business of the academy is conducted in the highest spirit of ethics and integrity.

Section 2. If any member of the Board of Managers or the Executive Committee is found by a vote of two-thirds of the Board of Managers to have violated the

spirit of ethics and integrity or the conflict of interest requirements, he or she shall be removed from office.

Section 3. The position vacated by such removal shall be filled temporarily by appointment by the Board of Managers until the next general scheduled election or regulation appointment to the affected position.

ARTICLE IX. COOPERATION

Section 1. The term ''Affiliated Societies'' shall be held to cover the current Affiliated Societies and such others as may hereafter apply for affiliation, are recommended by the Policy Planning Committee, approved by the Board of Managers and elected by two-thirds of the members of the Academy voting, the vote being taken by correspondence. A society may be released from affiliation on approval by the Board of Managers, upon a written request to the President or the Vice President for Affiliate Affairs.

Section 2. The Academy may assist the Affiliated Societies in any matter of common interest, as in joint meetings, or in the publication of a joint directory; provided it shall not have power to incur for or in the name of one or more of these societies any expense or liability not previously authorized by said society and societies, nor shall it, without action of the Board of Managers, be responsible for any expenses incurred by one or more of the Affiliated Societies.

Section 3. No Affiliated Society shall be committed by the Academy to any action in conflict with the charter, constitution, or bylaws, of said society, or its parent society.

Section 4. The Academy may establish and assist a Washington Junior Academy of Sciences for the encouragement of interest in science among students in the Washington area of pre-college and college age.

ARTICLE X. AWARDS AND GRANTS-IN-AID

Section 1. The Academy may award medals and prizes or otherwise express its recognition and commendation of scientific work of high merit and distinction in the Washington area. Such recognition shall be given only on approval by the Board of Managers of a recommendation by the Committee on Awards for Scientific Achievement.

Section 2. The Academy may receive or make grants to aid scientific research in the Washington area. Grants shall be received or made only on approval by

the Board of Managers of a recommendation by the Committee on Grants-in-Aid for Scientific Research.

ARTICLE XI. AMENDMENTS

Section 1. Amendments to these bylaws shall be proposed by the Board of Managers and submitted to the members of the Academy in the form of a mail ballot accompanied by a statement of the reason for the proposed amendment. A two-thirds majority of those members voting is required for adoption. At least two weeks shall be allowed for the ballots to be returned to the Secretary.

Section 2. Any Affiliated Society for any group of ten or more members may propose to the Board of Managers an amendment to the Bylaws in writing. The action of the Board of Managers in accepting or rejecting this proposal to amend the bylaws shall be by a vote on roll call, and the complete roll call shall be entered in the minutes of the meeting.

ARTICLE XII. DISTRIBUTION OF FUNDS ON DISSOLUTION

In the event of a liquidation, dissolution, or termination of the Washington Academy of Sciences (whether voluntary, involuntary, or by operation of law), the total assets of the Washington Academy of Sciences shall be distributed by the Board of Managers, provided that none of the property or assets of the Washington Academy of Sciences shall be made available in any way to any individual, corporation or other organization, except to one or more corporations, or other organization which qualify as exempt from federal income tax under Section 501(c)(3) of the Internal Revenue Code of 1954, as may be from time to time amended.

ARTICLE XIII. CONTROL OF FUNDS, ACTIVITIES

No part of the net earnings of the Washington Academy of Sciences shall inure to the benefit of, or be distributable to its members, trustees, officers, or other private persons, except that the Washington Academy of Sciences shall be authorized and empowered to pay reasonable compensation for services rendered, and to make payments and distributions in furtherance of the purposes set forth in Article XII hereof. No substantial part of the activities of the Washington Academy of Sciences shall involve the carrying on of propaganda, or otherwise at-

tempting to influence legislation. The Washington Academy of Sciences shall not participate in, or intervene in (including the publishing or distribution of statements) any political campaign on behalf of any candidate for public office. Notwithstanding any other provision of these Articles, the Washington Academy of Sciences shall not carry on any other activities not permitted to be carried on (a) an association excempt from Federal income tax under section 501(c)(3) of the Internal Revenue code of 1954 (or the corresponding provision of any future United States Internal Revenue Law) or (b) by an association, contributions to which are deductible under Section 170(c)(2) of the U.S. Internal Revenue Code of 1954 (or the corresponding provision of any future United States Internal Revenue Law).

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Special offer on Biography of Charles Doolittle Walcott, President of the Washington Academy of Sciences, 1899–1910

DELEGATES TO THE WASHINGTON ACADEMY OF SCIENCES, REPRESENTING THE LOCAL AFFILIATED SOCIETIES

Acoustical Society of America	Tim Margulies
American Association of Physics Teachers	Frank R. Haig
American Ceramic Society	Laurie George
American Fisheries Society	Ramona Schreiber
American Institute of Aeronautics and Astronautics	Reginald C. Smith
American Institute of Mining, Metallurgical, and Petroleum Engineers	Michael Greeley
American Meteorological Society	A. James Wagner
American Nuclear Society	Paul E. Thiess
American Phytopathological Society	Kenneth L. Deahl
American Society of Microbiology	VACANT
American Society of Civil Engineers	John N. Hummel
American Society of Mechanical Engineers	Daniel J. Vavrick
American Society of Plant Psychologists	VACANT
Anthropological Society of Washington	Marilyn London
ASM International	Toni Marechaux
Association for Computing Machinery	Lee Ohringer
Association for Science, Technology, and Innovation	Isaac Welt
Biological Society of Washington	Janet W. Reid
Botanical Society of Washington	Ray Peterson
Chemical Society of Washington	Elise Ann B. Brown
District of Columbia Institute of Chemists	VACANT
District of Columbia Psychology Association	David Williams
Eastern Mineral Resource Surveys Team	VACANT
Eastern Sociological Society	Ronald W. Mandersheid
Electrochemical Society	VACANT
Entomological Society of Washington	F. Christian Thompson
Geological Society of Washington	Bob Schneider
Helminthological Society of Washington	VACANT
Historical Society of Washington, DC	Phillip Ogilivie
Human Factors and Erogonomics Society	Thomas B. Malone
Institute of Electrical and Electronics Engineers	Rex C. Klopfenstein
Institute of Food Technologists	Isabel Walls
Institute of Industrial Engineers	Neal Schmeidler
Instrument Society of America	John I. Peterson
International/American Association of Dental Research	J. Terrell Hoffeld
Mathematical Association of America	Sharon K. Hauge
Medical Society of the District of Columbia	Duane Taylor
National Capital Astronomers	Harold Williams
National Geographic Society	VACANT
Optical Society of America	William R. Graver
Pest Science Society of Washington	VACANT
Philosophical Society of Washington	James Goff
Society for General Systems Research	VACANT
Society of American Foresters	Michelle Harvey
Society of American Military Engineers	VACANT
Society of Experimental Biology and Medicine (SEBM)	C. R. Creveling
Society of Manufacturing Engineers	VACANT
Technology Transfer Society	Clifford Lanham
Washington History of Science Club	Albert G. Gluckman
Washington Operations Research/Management Science Council	John G. Honig
Washington Paint Technical Group	Robert Kogler
Washington Society of Engineers	Alvin Reiner
Washington Statistical Society	Michael P. Cohen

Delegates continue to represent their societies until new appointments are made.

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